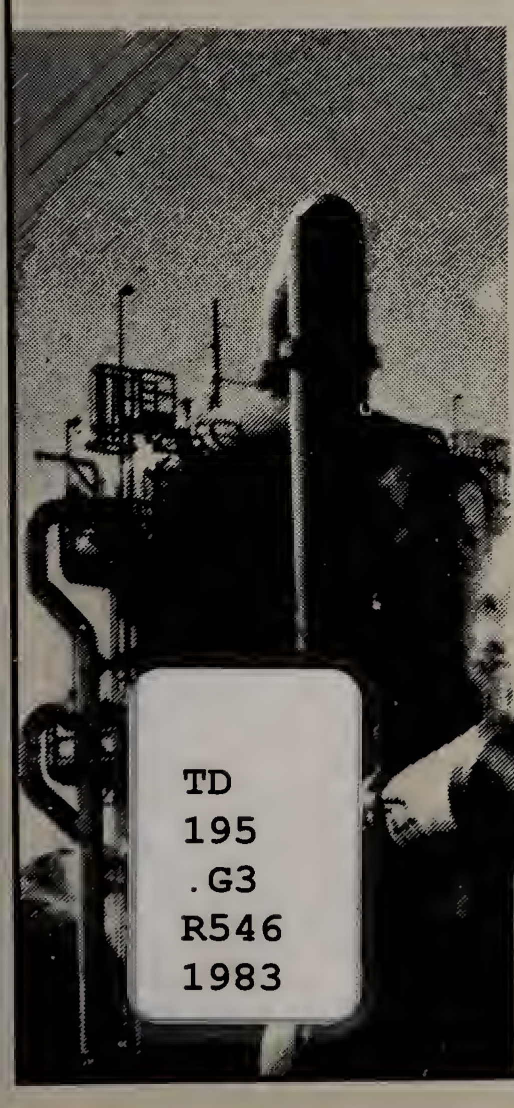
RILEY RIDGE NATURAL GAS PROJECT

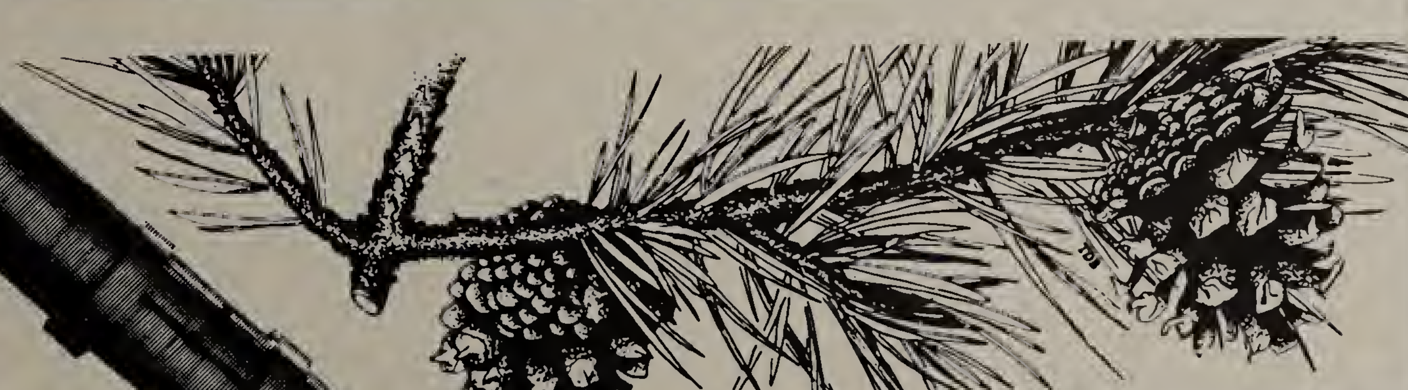
HEALTH AND SAFETY TECHNICAL REPORT

MAY 1983

Prepared by:
ENVIRONMENTAL RESEARCH
AND TECHNOLOGY, INC. for

DEPARTMENT OF INTERIOR
BUREAU OF LAND MANAGEMENT
DEPARTMENT OF AGRICULTURE
FOREST SERVICE





HEALTH AND SAFETY TECHNICAL REPORT
FOR THE RILEY RIDGE
ENVIRONMENTAL IMPACT STATEMENT

April 1983

Principal Preparers: Ann Berman, Manager, Energy Development
John Caban
Arthur Bass
Environmental Research & Technology, Inc.

For Further Information Contact: Bureau of Land Management
Division of Environmental Impact Statement Services
555 Zang Street, First Floor East
Denver, Colorado 80228

This technical report was reviewed by agency specialists included in the List of Preparers in the Riley Ridge Draft Environmental Impact Statement.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

LIST OF TABLES (CONTINUED)

LIST OF FIGURES

CHAPTER 1

AFFECTED ENVIRONMENT

Health and safety considerations are related primarily to public and worker exposure to hydrogen sulfide gas (H_2S) in excess of acceptable levels. This chapter describes effects of exposure to H_2S and identifies categories of individuals who could potentially be exposed to H_2S.

HYDROGEN SULFIDE PROPERTIES AND EXPOSURE EFFECTS

PHYSICAL CHARACTERISTICS

Hydrogen sulfide is a colorless gas with an offensive odor suggestive of rotten eggs. The molecular weight of H_2S is approximately 34, and its specific gravity is about 1.2 (air = 1). H_2S boils at about -60°C and freezes at -84°C. It is a highly flammable gas with explosive limits of 4.3 percent and 46 percent by volume of air.

EFFECTS OF HUMAN EXPOSURE TO H_2S

Hydrogen sulfide is an acute acting, extremely toxic gas. Exposures at very high concentrations have been documented to cause unconsciousness, respiratory paralysis, and death (American Conference of Government Industrial Hygienists 1980). Research shows that at low concentrations, H_2S alone or in combination with other chemical substances can cause temporary nervous system, cardiovascular, and gastrointestinal disorders, and can affect the eyes (National Institute for Occupational Safety and Health 1977), but no conclusive evidence exists that adverse health effects occur from repeated long-term exposure to H_2S at low concentrations.

The toxicity data shown in Table 1-1 for H_2S and various other gases indicate that H_2S is far more toxic than either carbon dioxide or methane, the other major constituent gases in the Riley Ridge area. The specific physical effects at various H_2S exposure levels are presented in Table 1-2. The data show that at a level of 100 parts/million, the eyes and throat may sting and the sense of smell may be lost within 2 to 15 minutes. At 500 parts/million, breathing generally ceases within a few minutes and artificial respiration is required immediately. In most instances exposure to levels of 1,000 parts/million results in immediate unconsciousness and death within minutes.

CORROSION EFFECTS

Hydrogen sulfide is a highly corrosive gas, especially in the presence of water. When steel is exposed to H_2S in the absence of air, iron sulfide is formed. Iron sulfide when exposed to air may create a fire hazard due to spontaneous combustion.

When water is present, hydrogen becomes a by-product of the corrosion process. Hydrogen can enter the steel, causing embrittlement. A stress applied to the steel may cause corrosion cracking. Thus, the presence of H_2S may increase the probability of leak or rupture of pipes, valves, etc.

TABLE 1-1

HAZARDOUS AND LETHAL CONCENTRATION LIMITS

Common Name	Chemical Formula	Specific Gravity	Hazardous[1] Limit	Lethal[2] Concentration
Hydrogen cyanide	HCN	0.940	150 ppm/hr[3]	300 ppm
Hydrogen sulfide	H_2S	1.176	250 ppm/hr	600 ppm
Sulfur dioxide	SO_2	2.210	--	1,000 ppm
Chlorine	Cl_2	2.450	4 ppm/hr	1,000 ppm
Carbon monoxide	CO	0.970	400 ppm/hr	1,000 ppm
Carbon dioxide	CO_2	1.520	5%	10%
Methane	CH_4	0.550	Combustible above 5% in air	--

Source: American Petroleum Institute. 1978. Safe drilling of wells containing hydrogen sulfide. Washington, D.C.

[1]Hazardous Limit - concentration that may cause death.

[2]Lethal Concentration - concentration that will cause death with short-term exposure.

[3]ppm - parts per million

TABLE 1-2

PHYSIOLOGICAL EFFECTS OF HYDROGEN SULFIDE

H_2S Percent (ppm)[1]	0-2 Minutes	2-15 Minutes	15-30 Minutes	30 Min.- 1 Hour	1-4 Hours	4-8 Hours	8-48 Hours
0.005 (50) 0.010 (100)				Mild eye irritation; respiratory tract irritation			
0.010 (100) 0.015 (150)		Coughing; irritation of eyes; loss of sense of smell	Disturbed respiration; pain in eyes; sleepiness	Throat irritation	Salivation & mucous discharge; sharp pain in eyes; coughing	Increased symptoms[2]	Hemorrhage & death[2]
0.015 (150) 0.020 (200)		Loss of sense of smell	Throat & eye irritation	Throat & eye irritation	Difficult breathing; blurred vision; light shyness	Serious irritating effects	Hemorrhage & death
0.025 (250) 0.035 (350)	Irritation of eyes; loss of sense of smell	Irritation of eyes	Painful secretion of tears; weariness	Light shyness; nasal catarrh; pain in eyes; difficult breathing	Hemorrhage & death[2]		
0.035 (350) 0.045 (450)		Irritation of eyes; loss of sense of smell	Difficult respiration; coughing; irritation of eyes	Increased irritation of eyes and nasal tract; dull pain in head; weariness; light shyness	Dizziness; weakness; increased irritation; death	Death[2]	
0.050 (500)	Coughing; collapse & unconsciousness	Respiratory disturbances; irritation of eyes; collapse	Serious eye irritation; palpitation of heart; few cases of death[2]	Severe pain in eyes and head; dizziness; trembling of extremities; weakness & death[2]			
0.060 (600) 0.070 (700) 0.080 (800) 0.100 (1000) 0.150 (1500)	Collapse[2]; unconsciousness; death[2]	Collapse[2]; unconsciousness; death[2]					

[1]ppm - parts per million.

[2]Data secured from experiments with dogs which have a susceptibility similar to men.

CATEGORIES OF INDIVIDUALS

There are three distinct categories of individuals of concern in the health and safety analysis. They are:

- Employees of the applicants or contractors. Included are: construction workers, well field employees, and employees working in the treatment plants or anywhere exposure might result.

- Certain individuals from the general public who could potentially be present near sour gas facilities. These include ranchers, hunters, snowmobilers, residential dwellers not in established communities, and users of recreational facilities in the area (such as Fontenelle Reservoir).

- Persons living in communities near facilities associated with sour gas operations. The facilities include pipelines, well fields, and treatment plants.

The categories of individuals identified above have been inventoried in the Socioeconomic Technical Report prepared for the Riley Ridge Project. The projected population distribution in the study area for 1990 is shown on Table 1-3. Map 1-3 in the Environmental Impact Statement (EIS) illustrates the locations of the populated areas in relation to project components.

Certain sensitive segments of the population are of particular concern in estimating human health and safety impacts. These sensitive individuals include the elderly, young children, those in hospitals and institutions, and those with respiratory problems. Exposure to H_2S will generally have greater impact on these individuals than other members of society. Typically, discomfort for sensitive individuals will occur at H_2S levels below those experienced by the general public.

The risk assessments described in this report are based throughout on conservative assumptions (including, for example, sets of "worst-case" meteorological scenarios) in order to estimate the most severe impacts that could reasonably occur. For this reason, the risk assessments presented here should not be interpreted as likely outcomes, but rather as possible but improbable impacts. To assist the reader in interpreting the risks reported in this document, corresponding risks for activities for various other accidents and national disasters are presented in Table 1-4.

Geologic Hazard

The Riley Ridge Project would be located in an area of low to moderate seismic activity, the well field having moderate activity with the area east and south of the well field having low activity. No specific fault analysis along pipeline routes has been conducted; however, the pipeline rupture information presented in Chapter 3 does include ruptures from earth movement. Thus, the pipeline rupture probability used for risk assessment includes pipeline ruptures from geologic hazards as part of the basic data base.

TABLE 1-3

POPULATION INVENTORY FOR RILEY RIDGE PROJECT

Population Category	Estimated 1990 Population[1]
Construction Workers	0 (Northwest), 406 (Exxon) 16 (Quasar)
Gas Treatment Plants	319 (Exxon), 82 (Northwest), 150 (Quasar)
Well Field Workers	40 in well field (Mobil)[3] 68 in well field (Quasar)[4] 163 in well field (Exxon)[5] 59 in well field (Willams)
LaBarge	1,206
Big Piney	1,177
Marbleton	1,134
Fontenelle Recreation Area[2]	1,210
Calpet	54

[1]Peak construction would occur in 1986.

[2]Peak day use in 1980.

[3]Includes those employed in Northwest's gathering system operation.

[4]Includes those employed in Quasar's pipeline operation.

[5]Includes those employed in Exxon's pipeline operations.

TABLE 1-4

ANNUAL INDIVIDUAL RISK OF DEATH FROM VARIOUS ACCIDENTS AND NATURAL DISASTERS

Risk-Producing Activity	Risk
• Smoking (20 Cigarettes/Day)	0.005
• Automobile	0.00025
• Industrial	0.00017
• Falls	0.000077
• Fire and Burns	0.00004
• Airplane Crashes	0.0000077
• Lightning	0.0000005
• Tornadoes	0.00000044

Source: Atwell and Andrews 1979.

SIGNIFICANCE CRITERIA

The dominant health and safety concern associated with the Riley Ridge Project is the accidental discharge of H_2S to the atmosphere, because exposure to concentrated levels of H_2S can result in serious health-related impacts or death. Other health and safety concerns, which include injury from fires and explosions, exposure to dangerous levels of CO_2, or injury from spills or ruptures of liquid sulfur pipelines, are by comparison deemed insignificant for the general public, but such dangers cannot be entirely discounted. Although detailed analyses have not been done, it is expected that adequate physical security and access control precautions should amply contain these other risks to acceptably minimal levels for individuals from the general public.

Health and safety impacts from H_2S releases would be considered significant if exposure is likely to impair the sense of smell, irritate the eyes, or affect respiration. Exposure to 100 parts/million H_2S for 15 minutes is likely to cause these levels of discomfort, but is generally recognized to be a sublethal dose. Exposure to 250-500 parts/million H_2S for two minutes or less may also cause similar degrees of olfactory, visual, or respiratory distress, and may also be lethal to unusually sensitive individuals (see Table 1-2). Because of the complicated nature of initial releases and subsequent dispersion of H_2S from large and small sour gas lines, in some cases the 100 parts/million, 15-minute average concentrations extend farther downwind than do the 250 parts/million, 2-minute average or 500 parts/million, instantaneous concentrations. In other cases (usually for smaller pipeline diameters and/or shorter block valve spacings) the situtation may be reversed -- the 250 parts/million, 2-minute average or 500 parts/million, instantaneous concentrations, extend farther downwind than the 100 parts/million, 15-minute average concentration. For this reason the Health and Safety H_2S Significance Criterion may differ from situation to situation. The conservative approach used here is always to choose from among these three dosages, the one which correponds to the greatest downwind distance (or range of impact) in a given situation. In any event, the Significance Criterion used here corresponds conservatively to exposures that may lead to hospitalization.

Of greater concern, one which goes well beyond the question of Health and Safety 'significance' is the possibility of lethal doses. Exposure to 1,000 parts/million of H_2S, even for an instant, is generally taken to be a lethal dosage unless immediate, extraordinary measures are taken to revive the victim (see Table 1-2). This exposure level is used to identify where design changes should be priority areas, and where adequate mitigation may require possible design alternatives.

Because of unavoidable technical uncertainities encountered in modeling the transient release of H_2S (especially from the smaller pipe sizes), it is not always possible to distinguish very well between the extent of the

500 parts/million, instantaneous concentration, and the 250 parts/million, 2-minute average concentration. Because they are generally comparable and the technical uncertainties preclude knowing which is the more reliable, for uniformity and ease of analysis, only the extent of the 500 parts/million, instantaneous concentration was used for comparisons with the extent of the 100 parts/million, 15-minute average concentration.

For this analysis, therefore, persons located beyond the extent of the 500 parts/million, instantaneous concentration or the 100 parts/million, 15-minute average concentration (whichever is farther) are considered to be outside the region of significant impacts. Persons located between the extent of the 1,000 parts/million, instantaneous concentration, and the 500 parts/million, instantaneous or 100 parts/million, 15-minute concentrations (whichever is nearer), could be exposed to lethal doses (depending on the health of the individual) and would experience discomfort. Persons located within the extent of the 1,000 parts/million, instantaneous concentration could be exposed to lethal doses.

WELL FIELD ASSESSMENT

DESCRIPTION OF WELL FIELD DRILLING

Table 2-1 summarizes the proposed well field development, and the drilling schedule by year is shown on Table 2-2.

Well field development begins with drilling and cementing of conductor and surface casings. Conductor casings are about 36 inches in diameter and extend 40 to 80 feet below the surface. Surface casings, which extend to depths of 2,000 to 4,000 feet, are 17 to 18 inches in diameter. After the surface casing is cemented, drilling continues, intermediate casings are cemented, and the production hole is drilled. Drill-stem testing is conducted prior to setting the last casing; then the last casing is cemented in place and gun perforated. Further tests may be conducted prior to bringing the well on line.

SAFETY MEASURES REQUIRED OF THE APPLICANTS BY VARIOUS AGENCIES

The Bureau of Land Management (BLM) has established instructions and guidelines for H_2S safety where operation on federal mineral lands requires handling of products containing H_2S. The guidelines cover three basic areas of safety: personnel safety, public safety, and the use of proper equipment in an H_2S environment. The BLM checklist utilized for review of drilling and production facilities is displayed in Appendix A. Upon receipt of an Application for Permit to Drill (APD), the District Supervisor (DS) will determine if the well may penetrate a formation bearing H_2S. If H_2S release may be anticipated, the DS will request an H_2S contingency plan from the operator. The DS will then review and approve the contingency plan before considering approval of the APD. The DS will, upon the approval of the APD, inspect, observe, and record the presence or absence of protective personnel equipment; an operating automatic H_2S detection system; displayed warning signs and flags; weekly safety meetings; and other procedures and equipment described in the operator's approved contingency plan (Minerals Management Service 1982).

TABLE 2-1

DESCRIPTION OF WELL FIELDS

Company	Total Number of Proposed Wells	General Locations of Units	Nominal Well Flow Rates[1]	Nominal Well Flowing Pressures[2]
Quasar	72	Riley Ridge, North Riley Ridge (Proposed), Darby Mountain (Proposed)	15	1,500-2,000
Exxon	75	Lake Ridge, Fogarty Creek, Graphite, Dry Piney, Dry Piney Annex (non-unitized)	20	2,200
Williams	24	Sawmill Area (non-unitized)	10-15	
Mobil	67	Tip Top, Hogsback	15-20	2,000-3,500

[1]Million cubic feet/day.

[2]Pounds/square inch.

TABLE 2-2

RILEY RIDGE DRILLING SCHEDULE BY YEAR

Year	Mobil	Quasar	Exxon	Williams
	Tip Top & Hogsback Units	Riley Ridge, North Riley Ridge[1] & Darby Mountain [1] Units	Lake Ridge, Fogarty Creek, Graphite Units Dry Piney, Dry Piney Annex[2]	Sawmill Area[2]
1980	4	0	0	0
1982	2	6	3	0
1983	2	4	3	0
1984	2	4	6	4
1985	2	6	6	4
1986	2	13	6	4
1987	2	13	6	4
1988	2	13	6	4
1989	2	13	6	4
1990	2		6	
1991	2		6	
1992	2		6	
1993	3		6	
1994	3		6	
1995	3		3	
1996	3			
1997	3			
1998	3			
1999	3			
2000	2			
2001	2			
2002	2			
2003	2			
2004	2			
2005	2			
2006	2			
2007	2			
2008	2			
2009	2			
TOTAL	67	72	75	24

[1]Proposed Units.

[1]Non-unitized.

The BLM provides numerous guidelines for the enforcement of proper precautions to be used in drilling and production operations in a potential H_2S environment. The guidelines specify various Incidents of Non-Compliance (INCs) and the specific enforcement actions required. The enforcement procedures generally require two basic actions: warning or shut down.

The H_2S contingency plan presented to the BLM by the operator must fully describe the safety precautions necessary to preserve life and property. The following requirements must be included in an acceptable contingency plan:

- Safety procedures -- including use and maintenance of all production and monitoring equipment, special handling and storage requirements in H_2S environments, and smoking rules

- Safety equipment -- including specifications, supplies, locations, uses and maintenance of all breathing apparatus and other protective equipment

- Flares and other ignition equipment

- Mud scavenging materials and equipment

- H_2S warning systems -- including automatic H_2S detectors, alarm sirens and bells, remote warning devices

- Designation of two safety briefing areas, one upwind at any time

- Safety training -- including procedures for shutting in and evacuation, securing of equipment, responsibilities and duties of all personnel onsite and offsite

- Formal security plan -- including fences, markers, physical barriers, security personnel

- Formal emergency evacuation/public warning plan -- including emergency phone numbers and notification of local public safety and medical personnel, government officials and agencies, schools and other public facilities, nearby residents and visitors, and others to be notified in the event of an H_2S emergency.

In addition to the previous rules and guidelines, the American Petroleum Institute (API) has issued "Recommended Practices for Safe Drilling of Wells Containing Hydrogen Sulfide" (API Recommended Practices #58, 1978). Conformance to these guidelines is recommended whenever there is a reasonable expectation of encountering H_2S gas-bearing zones that could result in atmospheric concentrations of 20 parts/million or more of H_2S.

The API has also published a document titled "Conducting Oil and Gas Production Operations Involving Hydrogen Sulfide" which presents recommended guidelines for the safe production, processing, and transportation of natural gas containing H_2S (API Recommended Practices #59, 1981). These guidelines, based on results of years of industry experience, apply to gas

producing, gathering, treating, storage, leasing, transportation, and gas sweetening plants in the presence of H_2S at concentrations potentially in excess of 20 parts/million.

OSHA guidelines provide standards for the institution of emergency rescue procedures; the use, maintenance, and inspection of respirators; and protective equipment to be used at facilities where the potential for H_2S exposure exists. A respiratory protection program should include: regular personnel training, maintenance, inspection, cleaning, and evaluation. The OSHA standards also address eye and face protection, occupational head protection, occupational foot protection, and electrical protective devices in accordance with the Occupational Safety and Health Act of 1970 (OSHA 1978).

Each applicant's proposed H_2S drilling and safety procedures are summarized in Table 2-3. Specific details clarifying operational safety measures are described below.

Sour gas (H_2S) is not likely to be encountered until drilling at intermediate depths. For this reason, after the surface casing is set, a blowout preventer must be installed as an operational safety measure. A blowout preventer is a combination of hydraulically controlled ram-type and bag-type mechanisms which closes around the pipe (or open-hole if pipe is out of hole) to seal off the well.

The drilling mud is also important to operational safety. The weight of the mud would be carefully controlled to balance the well field pressure encountered during drilling. The pH of the mud should be maintained at 10 or more to reduce corrosion caused by organic acids and H_2S. Zinc carbonate or other H_2S scavengers are then added to the mud to precipitate H_2S. It is assumed that concentrations of 1 to 5 pounds/barrel of an H_2S scavenger, such as zinc carbonate, would be added to the mud prior to drilling into the H_2S-producing formation. An additional 1 to 2 pounds/barrel excess should be added after each new influx of H_2S.

During drill-stem completion or production testing, an elevated flare stack (commonly used for H_2S gas) would be brought into the field and sufficient propane would be stored to inject into the field gas to ensure burning. A ratio of 10:1 low BTU sour gas to sweet gas, would be sufficient for this purpose.

Corrosion rings are to be placed on the drilling strings above the drill collars and in the kelly saver sub from spud to total depth. It is assumed that these rings would be inspected every 100 to 150 hours for corrosion damage. Water should be sprayed on the bottom of pipe stands as a precaution against spontaneous combustion of iron sulfide.

WELL FIELD BLOWOUT RISK ASSESSMENT

Historic information on blowouts in well fields from drilling and production operations was obtained from various sources. These data provided an indication of the approximate probability of a well blowout during drilling and production operations. The specific information used is presented in Chapter 3, Methodologies. The methodology used to apply these historical blowout rates to the Riley Ridge Project is also described in Chapter 3.

TABLE 2-3

H_2S DRILLING PROCEDURES AND CONTINGENCY PLANS

Element	Quasar	Exxon	Williams	Mobil
• Formal Contingency Plan	X	X	X	*
• Safety and Emergency Response Training				
- Full H_2S safety training and education for all essential drilling personnel	X	X	*	*
- Safety drills per crew	X (weekly)	X (weekly)	*	*
- Advance briefings of public within area of exposure prior to drilling into sour gas formations	X	X	*	X
- Periodic tests of fire water system and fire drills	*	X	*	*
• Safety Equipment				
- Fixed and portable breathing equipment	X	X	X	X
- Automatic H_2S detectors	X	X	X	X
- Alarms and warning lights	X	X	X	X
- Portable H_2S detectors	X	*	X	X
- Explosion meters	X	*	X	X
• Drilling Operations				
- Use approved casing strings of rated strengths to meet minimum DOT safety requirements	X	X	X	*
- Maintain chemical properties and weight of drilling mud	X	X	*	*
- Install hydraulic BOP[1] during drilling operations	X	X	X	X

TABLE 2-3 (CONTINUED)

Element	Quasar	Exxon	Williams	Mobil
- Periodic BOP inspection and testing	X (daily)	X (weekly)	X (daily)	X (weekly)
- Traffic control during drilling operations	X	*	*	*
- Install downhole safety valve	*	X	*	*
• Production Operations				
- Inject anticorrosion fluids at wellhead	X	*	*	*
- Install pressure controlled BOP to shut in well in event of abnormal (high, low) line pressure	X	*	X	*
• Physical Security				
- Security plan	*	X	*	*
- Fences, etc.	*	*	*	*
- Guard fence	*	X	*	*
• Emergency Plan				
- Evacuation plan for required personnel	X	X	X	*
- Wind socks	X	X	X	X
- Designated safety briefing areas	X (2)	X (2)	X (1)	*
- Designated emergency routes	X	X	X	X
- Current lists of emergency manpower and equipment	X	X	*	*
- Plan to alert general public within exposure area	X (3-mi radius)	X	*	X

TABLE 2-3 (CONTINUED)

Element	Quasar	Exxon	Williams	Mobil
- Plan to alert public safety personnel	X	X	X	X
- Lists of emergency phone numbers	X	X	X	X
- Warning signs at public and access roads accessible to exposure area	X	*	*	*
- Plans to block public and access roads	X	X	X	X
- Plan to evacuate unauthorized personnel	X	X	*	*
- Well ignition protocol	X	X	X	*
- Intercom communications	X	*	X	X
- Augment guard fence	*	X	*	*

* Not explicitly specified in rights-of-way applications.

[1]Blowout preventer.

The results and estimates, expected to be conservative, show that for an individual well the probability of blowout during drilling is 0.0016 or 0.16 percent, and the probability of blowout during a producing year is 0.00033 or 0.033 percent. There is an expectation that 2.8 blowouts would occur during the producing lifetime of the project (30-40 years).

A blowout modeling analysis was undertaken to estimate the health impacts that could occur as a consequence of a blowout. For this purpose a generic blowout was postulated from information provided by the applicants. The results, which are described in detail in Chapter 3, show that the H_2S levels from a blowout are highly sensitive to the prevailing meteorological conditions and the assumed height of the release. Conservative assumptions regarding these variables show that, depending on the H_2S content of the gas, any persons within about 1 to 2 miles of the well could be exposed to significant levels of H_2S of at least 100 parts/million for 15 minutes. Individuals within about 0.25 to 0.50 miles of the well could be subjected to lethal levels of at least 1,000 parts/million.

The annual exposure risk to a person standing both downwind and within these distances during drilling is estimated to be less than 0.0003 (or 0.03 percent). During production the exposure risk per year is estimated to be less than 0.00002 (or 0.002 percent). These risks are roughly equivalent to the United States 1978 automobile death rate and fire and burn death rate, respectively (see Table 1-4).

PIPELINE ASSESSMENT

DESCRIPTION OF PIPELINE SYSTEM

Table 2-4 summarizes the principal size and total length characteristics of the gathering system and sour gas trunk lines according to presently available information. The rights-of-way of individual pipeline segments are shown on Map 1-3 in Chapter 1 of the EIS. The distribution of pipeline sizes is not presently available for Northwest/Mobil and Williams.

SAFETY MEASURES REQUIRED BY VARIOUS AGENCIES

The primary operational safety measures include gas dehydration, corrosion allowances, injection of corrosion inhibitors, spacing of block valves, safety training, frequent inspections, and appropriate technical specifications. These measures and emergency contingency plans are summarized by applicant in Table 2-5. Rules and regulations for pipeline safety are described below.

The Natural Gas Pipeline Safety Act (NGPSA) of 1968, as amended, (49 USC 1671 et seq.) provides for the regulation of those facilities used in the transportation by pipeline of natural and other gases in or affecting interstate or foreign commerce. It authorizes exclusive federal safety authority over interstate and intrastate gas pipeline systems. The U.S. Department of Transportation (DOT) has been given overall responsibility for the safety regulation of all pipelines covered by the Act. Individual states may, however, assume safety regulatory jurisdiction over the interstate system within its boundaries (U.S. DOT Annual Reports 1980, 1979, 1977).

TABLE 2-4

RILEY RIDGE SOUR GAS GATHERING SYSTEMS AND TRUNK LINES

	Miles of Pipeline of Nominal Diameter (To Nearest Mile)															Plant Site
	4"	6"	8"	10"	12"	14"	16"	18"	20"	22"	24"	26"	28"	30"	36"	(Alternative)
Quasar																
• Gathering System		30	7	11	6	3	2	4		6		3				
• Sour Gas Trunk Lines														11		East Dry Basin Plant Site (Proposed Action)
															(25)	Buckhorn Plant Site (Buckhorn, Shute Creek, Northern Alternative)
• Block valve Spacing	-	3	3	3	3	3	3	3	-	6	-	3	5	10	10	
Northwest Pipeline/Mobil																
• Gathering System	Total length of gathering system is stated as 70-75 miles ranging 6"-24", but no present information as to breakout by pipe diameter is available.															
• Sour Gas Trunk Lines															43	Craven Creek Plant Site (Proposed Action, Buckhorn, and Shute Creek Alternatives)
															(8)	East Dry Basin (Northern Alternative)
• Block valve Spacing	-	1	1	3	3	-	5	-	5	-	-	-	-		2.5-5	
Exxon	87	8	9	-	13	-	7	-	57	-	32	-	-	(43)		Shute Creek Plant Site (Shute Creek Alternative)
• Block valve Spacing	3	3	3	-	4	-	3	-	10	-	10	-	-	10		
Williams	Total length of the gathering system and trunk lines is 39.5 miles, and pipeline diameter would range between 6 and 26 inches. Further breakdown is not available.															

TABLE 2-5

H_2S GATHERING SYSTEM AND TRUNK LINE SAFETY PROCEDURES[1]

Element	Applicant			
	Quasar	Exxon	Williams	Northwest/Mobil
• Pipeline Construction				
- Design and construction to conform to applicable design standards	X	X	X	X
- Safety during blasting				
> Training	X	*	*	X
> Safety manual	X	*	*	X
> Blanketing in human use areas	X	X	X	X
> Prior notification to abutters	X	X	X	X
> Controlled blasting and manual digging where blasting unsafe	X	X	X	X
- Welding and testing				
> Welding in accordance to standard	X	X	*	X
> Visual inspection	X	X	*	X
> Radiographic inspection	X	X	*	X
> Hydrostatic pressure testing	X	X	X	X
- Corrosion control and cathodic protection	X	X	X	X

TABLE 2-5 (CONTINUED)

Element	Applicant Quasar	Exxon	Williams	Northwest/Mobil
- Block valves spacing (miles)	X 10 (mainline)	X 3-10	* *	X 2.5 (population areas) 5 (remote areas)
- Closing time (seconds)	<60	20-120		60
• Pipeline Operational Safety				
- Aerial visual inspection of ROW	X	X	*Q*	X
- Ground patrol on regular schedule	X	X	*	*
- ROW markers	X	X	*	X
- H_2S pipeline detection and alarm systems	X	X	X	X
• Security	*	*	*	X

* Not explicitly specified in rights-of-way applications.

[1]49 CFR 190 Pipeline Safety Program Procedures

49 CFR 192 Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards

The DOT's pipeline safety regulatory program is administered currently by the Office of Pipeline Safety Operations (OPSO). The department's pipeline safety operating functions include: developing, approving, issuing, and enforcing compliance with safety regulations for the transportation of gas by pipeline; managing federal grants to aid states in conducting intrastate gas pipeline safety programs; improving the safety of transportation by pipeline; collecting, compiling, and analyzing pipeline safety and operating data; and conducting training programs for government and industry personnel. OPSO regulatory programs have been established to assure the continued safety in the design, construction, testing, operation, and maintenance of gas pipelines (U.S. DOT 1977).

The federal regulations contained in 49 CFR Part 191 require gas operators to report certain pipeline leaks and failures to OPSO. In addition, the regulations described in 49 CFR Part 192 address the design, construction, testing, operations, and maintenance of any gas pipeline facilities used in the transportation of natural gas. Section 5 of the NGPSA provides for state participation in the federal gas pipeline safety program either through filing a certificate of participation under Section 5(a) or by entering into an agreement under Section 5(b). To qualify for the 5(a) certification, a state must have adopted gas pipeline safety regulations at least as stringent as the federal standards, and in addition, provide for enforcement authority of those standards by injunctive and monetary sanctions. State agencies not meeting the criteria for 5(a) certification may enter into an agreement to undertake certain aspects of a gas pipeline safety program (U.S. DOT 1980).

PIPELINE RISK ASSESSMENT

Notwithstanding numerous safety measures for the pipeline system, it is nevertheless possible that a rupture may occur in the Riley Ridge area (see Chapter 3 for definitions of rupture types). Historical data describing past pipeline rupture statistics were used to quantify this probability. As detailed in Chapter 3, historical data on sour gas lines in Alberta, Canada, and on sweet gas lines in the United States support a rupture probability estimate of 0.0002 ruptures per pipeline mile-year (or one rupture per 5,000 mile-years). Historical data also suggest that ruptures occur more frequently in smaller pipes and in older pipes; however, the data are insufficient to quantify these effects.

Based on a rupture probability of 0.0002 ruptures per mile-year and the number of miles of gathering lines and trunk lines proposed by each applicant, the probability of ruptures was estimated using the methodology described in Chapter 3.

These probabilities are given in Tables 2-6 and 2-7 and show that there is a greater likelihood of a rupture in the gathering system than in the trunk lines, because there are more miles of pipeline in the gathering system. In any year there is about a 7 percent chance that one or more ruptures would occur in the gathering system, but there is only about a 1 percent chance that a trunk line would rupture. However, the possibility of a trunk line rupture is the more important concern, for the following reasons.

TABLE 2-6

PROBABILITY OF PIPELINE RUPTURES IN THE GATHERING SYSTEM

	Miles of Pipeline in the Gathering System	Probability of One or More Ruptures in a Year	Mile-Years in Gathering System[1]	Probability of One or More Ruptures During Project Lifetime
Quasar	72	0.014	2,160	0.35
Williams	27	0.005	810	0.15
Northwest	75	0.015	2,250	0.36
Exxon	213	0.042	8,520	0.82
TOTAL	387	0.074	13,740	0.94

[1]Exxon proposes a 40-year project lifetime. The remaining applicants propose a 30-year project lifetime.

TABLE 2-7

PROBABILITY OF TRUNK LINE RUPTURES

	Miles of Trunk Line	Probability of One or More Ruptures in a Year	Mile Years for Trunk Line	Probability of One or More Ruptures During the Project Lifetime
Quasar				
East Dry Basin	11	0.002	330	0.064
West Dry Basin (Alternative)	5	0.001	150	0.030
Buckhorn (Alternative)	25	0.005	750	0.139
Northwest				
Craven Creek	43	0.0086	1,290	0.227
East Dry Basin (Alternative)	8	0.0016	240	0.047
Buckhorn (Alternative)	21	0.0042	630	0.118
Exxon				
Shute Creek (Alternative)	43	0.0086	1,290	0.227

Gathering systems would generally be located in sparsely populated areas, whereas trunk lines would pass closer to local communities. Gathering systems would generally be constructed of smaller diameter pipes and the block valve spacing for gathering lines is usually less than for trunk lines. Therefore if a rupture were to occur, the mass of gas released would be less from a gathering line than from a trunk line. For these reasons the consequences of gathering line and trunk line ruptures are described separately below.

Gathering Line Rupture Consequences

An air quality model described in Chapter 3 was used to evaluate the consequences of a gathering line rupture. Because the effects of a gathering line rupture are relatively local (see below) and the gathering systems are not in the immediate vicinities of designated population areas, the consequences analysis could be made in a generic manner, that is, not tied to a specific location for a gathering line rupture. A sensitivity analysis revealed that the predicted concentrations are highly sensitive to the assumptions made about the initial rise of the released gas. The results are also sensitive to variations in the applicants' block valve spacing, pipeline diameters, pressures, and assumed gas H_2S content. However, in general the following conclusions can be drawn.

- Low wind speed stable atmospheric conditions result in the worst-case H_2S concentrations. These conditions are estimated to occur about 30 percent of the time.

- A rupture of a 4-inch pipeline is not likely to result in lethal H_2S doses. However, an individual located within about 0.1 mile (600 feet) might experience eye irritation or a loss of smell (discomfort).

- A rupture of a 6-inch pipeline could result in lethal doses to persons located within a few hundred feet. People within about 0.5 mile of the rupture could also experience discomfort.

- A 12-inch pipe, if ruptured, could cause lethal dose to a distance of about 0.25 to 1 mile depending on the prevailing weather conditions, specific pipeline design, and H_2S content of the gas.

- Larger pipes in the gathering system (18 to 26 inches) would have the greatest areal extent of impact if ruptured. Lethal dosages might be experienced to a distance of 4 miles, and discomfort might be experienced to 6 miles if prevailing meteorological conditions were adverse.

None of the applicants' alternatives would significantly affect the consequences described above.

Trunk Line Rupture Consequences

Proposed Action

The Proposed Action includes Quasar's plant at East Dry Basin, Exxon's plants at West Dry Basin and Big Mesa, and Northwest's plant at Craven

Creek. Two major sour gas trunk lines are proposed: Quasar's 11-mile trunk line to the East Dry Basin plant site and Northwest's 43-mile trunk line to Craven Creek. Exxon's trunk lines to the West Dry Basin and Big Mesa plant sites would be less than 30 inches in diameter and were considered as part of the gathering system.

Quasar proposes a 10-mile block spacing for its trunk line; Northwest proposes a 5-mile block spacing in rural areas and a 2.5-mile block spacing where the line passes populated areas.

An air quality impact model described in Chapter 3 was used to describe the distribution of H_2S that might occur in the event of a rupture of each proposed trunk line. The distribution of H_2S was estimated for three meteorological conditions: low wind speed stable conditions typical of clear nights; a moderate wind speed neutral condition typical of average conditions in the area; and a low wind speed unstable condition representative of summer afternoons.

Table 2-8 shows the modeling results expressed in terms of the distances from the trunk lines beyond which a person would not be exposed to lethal or significant H_2S concentrations. As shown, during unstable atmospheric conditions typical of summer afternoons, a person located downwind and within about 0.5 mile of a trunk line rupture would be likely to experience a significant exposure to H_2S. During stable atmospheric conditions (most likely to occur during the evening and early morning hours), a person could be exposed to a lethal dose within 2 to 3 miles of a trunk line rupture, and could experience discomfort out to downwind distances of 5 to 7 miles.

A quantitative risk assessment for the Proposed Action was undertaken to assess the risk of H_2S exposure in the populated areas of LaBarge, Big Piney, Marbleton, Calpet, and the Fontenelle Recreation Area. The results are shown in Table 2-9. In this table, as well as Tables 2-10, 2-11 and 2-12, the "individual annual risks" are described as the chance per year that any individual would experience that risk. For example, an annual risk of 0.00013 (the risk of discomfort at LaBarge as shown in Table 2-9) means that any resident at LaBarge would have slightly more than one chance in ten thousand of experiencing discomfort in any given year.

As seen in Table 2-9, only Calpet would be at risk of exposure to lethal levels from a trunk line rupture. (Calpet's annual individual risk is roughly equivalent to the annual risk of death from an automobile accident). The remaining populated areas are at risk only of discomfort, and then only during light wind stable meteorological conditions.

Buckhorn Alternative

The Buckhorn Alternative includes Quasar's plant at Buckhorn, Exxon's plants at West Dry Basin and East Dry Basin, and Northwest's plant at Craven Creek. This alternative also includes two major sour gas trunk lines: Quasar's 25-mile trunk line to the Buckhorn plant site, and Northwest's 43-mile trunk line to Craven Creek. Exxon's trunk lines to the East Dry Basin and West Dry Basin plant sites would be less than 30 inches in diameter and were considered as part of the gathering system.

TABLE 2-8

DOWNWIND DISTANCES FOR SIGNIFICANT H_2S EXPOSURES FROM RUPTURES OF TRUNK LINES

ALL ALTERNATIVES

Applicant	Trunk Line Diameter (inches)	Block Valve Spacing (miles)	Downwind Distance for Lethal Dose (miles)		
			Stable Atmosphere	Neutral Atmosphere	Unstable Atmosphere
Quasar	30	10	2.5	0.9	0.4
Northwest	30	5	2.9	1.1	0.5
	30	2.5	2.2	0.9	0.4
			Downwind Distance for Significant Dose (miles)		
Quasar	30	10	6.8	1.4	0.7
Northwest	30	5	5.6	1.7	0.7
	30	2.5	3.4	1.5	0.6

TABLE 2-9

ANNUAL RISK TO POPULATED AREAS

PROPOSED ACTION

Populated Area	Individual Annual Risk of Lethal Exposure[1]	Individual Annual Risk of Significant Impact[2]	Approximate Number of People (in 1990)[3]
LaBarge	negligible[4]	0.00013	1,206
Big Piney	negligible	0.00008	1,177
Marbleton	negligible	negligible	1,134
Calpet	0.00023	0.00037	54
Fontenelle Recreation Area	negligible	0.00018	1,210

[1]Risk values shown in this table, such as 0.00013, mean 13 chances per 100,000.

[2]Significant exposures are those that would cause eye irritation, coughing, loss of smell, or other discomfort.

[3]Includes people in incorporated and unincorporated areas.

[4]Negligible means that the modeling analysis indicates <u>no</u> risk.

TABLE 2-10

ANNUAL RISK TO POPULATED AREAS FROM BUCKHORN ALTERNATIVE

Populated Area	Individual Annual Risk of Lethal Exposure[1]	Individual Annual Risk of Significant Impact[2]	Approximate Number of People (in 1990)[3]
LaBarge	negligible[4]	0.00013	1,206
Big Piney	negligible	0.00040	1,177
Marbleton	negligible	negligible	1,134
Calpet	0.00023	0.00037	54
Fontenelle Recreation Area	negligible	0.00018	1,210

[1]Risk values shown in this table, such as 0.00013, mean 13 chances per 100,000.

[2]Significant exposures are those that would cause eye irritation, coughing, loss of smell, or other discomfort.

[3]Includes people in incorporated and unincorporated areas.

[4]Negligible means that the modeling analysis indicated no risk.

Quasar proposes a 10-mile block spacing for its trunk line; Northwest proposes a 5-mile block spacing in rural areas and a 2.5-mile block spacing where the line passes populated areas.

The modeling analysis was made as described for the Proposed Action, and a corresponding risk assessment for the Buckhorn Alternative was performed to assess the risk of H_2S exposure in the populated areas of LaBarge, Big Piney, Marbleton, Calpet, and the Fontenelle Recreation Area. The results are shown in Table 2-10. It was found that only Calpet would be at risk of exposure to lethal levels from a trunk line rupture. The remaining populated areas are at risk of discomfort only during light wind stable meteorological conditions.

Shute Creek Alternative

The Shute Creek Alternative includes Quasar's plant at Buckhorn, Exxon's plants at Shute Creek, and Northwest's at Craven Creek. This alternative includes three major sour gas trunk lines: Quasar's 25-mile trunk line to the Buckhorn plant site, Exxon's 43-mile trunk line to Shute Creek, and Northwest's 43-mile trunk line to Craven Creek.

Quasar and Exxon propose 10-mile block spacing for their trunk lines; Northwest proposes a 5-mile block spacing in rural areas and a 2.5-mile block spacing where the line passes near populated areas.

The modeling analysis was made as described for the Proposed Action, and a corresponding risk assessment for the Shute Creek Alternative was performed to assess the risk of H_2S exposure in the populated areas of LaBarge, Big Piney, Marbleton, Calpet, and the Fontenelle Recreation Area. The results are shown in Table 2-11. It was found that only Calpet and LaBarge would be at risk of exposure to lethal levels from a trunk line rupture. LaBarge's annual individual risk is smaller than the annual risk of death from an automobile accident. The remaining populated areas are at risk of discomfort only during light wind stable meteorological conditions.

Northern Alternative

The Northern Alternative includes Quasar's plant at Buckhorn, Exxon's plants at West Dry Basin and Big Mesa, and Northwest's plant at East Dry Basin. This alternative also includes two major sour gas trunk lines: Quasar's 25-mile trunk line to the Buckhorn plant site and Northwest's 8-mile trunk line to East Dry Basin. Exxon's trunk lines to the West Dry Basin and Big Mesa plant sites would be less than 30 inches in diameter and were considered as part of the gathering system.

Quasar proposes a 10-mile block spacing for its trunk line; Northwest proposes a 5-mile block spacing in rural areas and a 2.5-mile block spacing where the line passes populated areas.

The modeling analysis was made as described for the Proposed Action, and a corresponding risk assessment for the Northern Alternative was performed to assess the risk of H_2S exposure in the populated areas of LaBarge, Big Piney, Marbleton, Calpet, and the Fontenelle Recreation Area. The results are shown in Table 2-12. It was found that none of the populated areas would be at risk of exposure to lethal levels from a trunk line rupture.

TABLE 2-11

ANNUAL RISK TO POPULATED AREAS FROM SHUTE CREEK ALTERNATIVE

Populated Area	Individual Annual Risk of Lethal Exposure[1]	Individual Annual Risk of Significant Impact[2]	Approximate Number of People (in 1990)[3]
LaBarge	0.000068	0.00033	864
Big Piney	negligible[4]	0.00040	861
Marbleton	negligible[4]	negligible[4]	845
Calpet	0.00048	0.00093	40
Fontenelle Recreation Area	negligible	0.00043	1,210

[1]Risk values shown in this table, such as 0.00033, mean 33 chances per 100,000.

[2]Significant exposures are those that would cause eye irritation, coughing, loss of smell, or other discomfort.

[3]Includes people in incorporated and unincorporated areas.

[4]Negligible means the modeling analysis indicates <u>no</u> risk.

TABLE 2-12

ANNUAL RISK TO POPULATED AREAS FROM NORTHERN ALTERNATIVE

Populated Area	Individual Annual Risk of Lethal Exposure[1]	Individual Annual Risk of Significant Impact[2]	Approximate Number of People (in 1990)[3]
LaBarge	negligible[4]	negligible	1,212
Big Piney	negligible	0.00040	1,217
Marbleton	negligible	negligible	1,171
Calpet	negligible	negligible	56
Fontenelle Recreation Area	negligible	negligible	1,210

[1]Risk values shown in this table, such as 0.00040, mean 40 chances per 100,000.

[2]Significant exposures are those that would cause eye irritation, coughing, loss of smell, or other discomfort.

[3]Includes people in incorporated and unincorporated areas.

[4]Negligible means that the modeling analysis indicates <u>no</u> risk.

Big Piney alone would be at risk of discomfort only during light wind stable meteorological conditions.

TREATMENT PLANT AND ANCILLARY FACILITY ASSESSMENT

FIRE, EXPLOSION, AND WEATHER

Each of the proposed gas treatment plants would process flammable, explosive, toxic gas. The specific nature of the risks involved in processing sour gas is not well documented in the literature. Therefore, general experiences in the oil and gas industry and in the chemical process industry are used as surrogates to describe the potential health and safety hazards of the proposed plants to the general public. The U.S. Department of Labor, Bureau of Labor Statistics, maintains data on occupational injuries and illnesses in the United States by industry. Although data are not specifically collected for sour gas processing plants, they are available for the crude petroleum and natural gas industry as a whole. These data pertain primarily to those establishments engaged in operating oil and gas field properties, including such activities as drilling, operation of separators, and all other activities in the preparation or processing of oil and gas up to the point of shipment from the producing property. In 1979 and 1980 the crude petroleum and natural gas industry reported 5.4 and 3.8 incidences per 100 full-time workers annually, respectively, where an incident is defined as an injury or illness or lost work day.

The Industrial Risk Insurers have reported statistics on the frequency of various types of incidents in the petrochemical industry. Their data show that fire accounts for about 42 percent of all incidents. Explosions and severe weather account for 23 and 14 percent of the incidents reported, respectively. The remaining incidents were not specifically categorized in the Industrial Risk Insurers report.

Fires are generally caused by overflow of flammable gas, pipe or fitting failure, by electrical breakdowns or by cutting and welding. Arson is not expected to be a major concern in the Riley Ridge area. Statistical information from the chemical processing industry suggests that only about 4 percent of all major fires are caused by arson.

The primary cause of explosion is the rupture of equipment. At the proposed treatment plants this could be caused by overpressure or corrosion. Because the gas contains significant amounts of H_2S and CO_2, corrosion and embrittlement of the steel are potential hazards, particularly if water vapor is present. Rubber is also known to swell considerably in the presence of H_2S.

Severe weather in the project area potentially includes thunderstorms, tornadoes, and snow blizzards. The peak thunderstorm season is July and August. The record at Salt Lake City of 1929-1977 shows an average of 35 days per year with thunderstorms, and 15 of these days occur in July and August. Brief gusty winds and heavy rains generally accompany thunderstorms. Hail is common with well developed thunderstorms. Tornadoes are associated with the most severe thunderstorms and also squall lines in fast-moving cold fronts. In the entire state of Wyoming a total of

165 tornadoes were observed in the 52-year period 1916 through 1967. Almost 90 percent of these sightings occurred in May, June, and July. Two tornadoes and a funnel cloud have been sighted in the Rock Springs BLM District. Severe blizzards in the project area typically occur once every 3 to 4 years. Blizzards are usually associated with snow drifts and high winds, leading to road blockages and damage to power and communication lines. In most cases, the high winds cause more damage and disruption than does the amount of snowfall.

H_2S RELEASES

Each of the proposed sour gas treatment plants would have an emergency flare to combust toxic H_2S gas streams under plant upset conditions. The duration of a flaring event is estimated at one-half hour to one hour, and the annual frequency of upset conditions requiring flaring is estimated to range from 12 events per year for upset of an individual 200-million cubic feet/day (cfd) module, to 1 event per year for an entire 600-million cfd plant, according to information provided by the applicants. The likelihood of pipeline ruptures within gas treatment plants is considerably smaller than ruptures to the trunk line, and public access to the hazardous areas of the plants would be severely restricted in any case. Accordingly, because the proposed gas treatment plants are located well away from populated areas, and the likelihood of upset is small, there should be no risk of appreciable plant-related significant H_2S exposures to the general public.

SALES GAS LINES

As discussed in Chapter 3, the probability of a rupture in a sales gas line may be an order of magnitude greater than probabilities discussed for the sour gas gathering system and trunk lines, but the risks associated with rupture of the sales gas lines are essentially only those of fire and explosion in the immediate vicinity of the rupture. Release of sales gas to the atmosphere does not pose a significant risk to the general public because, except in the immediate area of the rupture, the methane would quickly disperse to concentrations below flammable limits. Accordingly, the risk of accident to the general public is considered negligible.

In summary, the hazards described above are not likely to affect the general public in the vicinity of the plants unless H_2S is released. Even in such an event, there is little likelihood that members of the general public would be in jeopardy.

PIPELINE RUPTURE ANALYSIS WITH ADDITIONAL BLOCK VALVES

One measure available to reduce H_2S impacts from trunk line ruptures would be the use of block valves to seal off a segment of ruptured pipeline. Block valves react to changes in pipeline pressure and close in a period ranging from a few seconds to a few minutes, depending on pipeline diameter. A quantitative risk assessment was conducted using the trunk line block valve spacings as specified by the applicants, as well as additional block valves spaced along trunk line segments near populated areas. The results are presented below.

PROPOSED ACTION WITH ADDITIONAL BLOCK VALVES

For the Proposed Action, the Quasar trunk line was modeled with 10-mile block valve spacing (as proposed) away from the designated populated areas

and 2-mile block valve spacing near population areas. Northwest's trunk line was modeled, as proposed, with 5-mile block valve spacing away from the population areas and 2.5-mile block valve spacing near the population areas. In addition, 1-mile block valve spacing near populated areas was investigated. Northwest's trunk line was modeled with shorter block valve spacings because the gas has a higher average H_2S content than is expected to occur in Quasar's gas field.

The modeling analysis was carried out as described previously and a corresponding risk assessment was performed for the Proposed Action with additional block valves. The population areas considered were LaBarge, Big Piney, Marbleton, Calpet, and the Fontenelle Recreation Area. The results are shown in Table 2-13. It was found that only Calpet would be at risk of exposure to lethal levels from a trunk line rupture, and that the use of additional block valves reduces the annual risk of lethal exposure by about 25 percent (from 0.00023 to 0.00018). The annual risk of discomfort exposure is reduced even more, about 33 percent (from 0.00037 to 0.00025). With this additional block valve spacing near the populated areas of LaBarge, Big Piney, Marbleton, and the Fontenelle Recreation Area, the annual risk of discomfort exposure declines to negligible.

BUCKHORN ALTERNATIVE WITH ADDITIONAL BLOCK VALVES

For the Buckhorn Alternative, the Quasar trunk line was modeled with 10-mile block valve spacing (as proposed) away from the designated populated areas. In addition, 2-mile block valve spacing near the population areas was investigated. Northwest's trunk line was modeled with 5-mile valve spacing (as proposed) away from the population areas and 2.5-mile near populated areas. In addition, 1-mile block valve spacing near the population areas was investigated.

The modeling analyses were carried out and a corresponding risk assessment was performed for the Buckhorn Alternative with additional block valves. The results, shown in Table 2-14, are identical to those described above for the Proposed Action with additional block valves.

SHUTE CREEK ALTERNATIVE WITH ADDITIONAL BLOCK VALVES

For the Shute Creek Alternative, the Quasar and Exxon trunk lines were modeled with 10-mile block valve spacing (as proposed) away from the designated populated areas, and as before, additional 2-mile block valve spacing near the population areas. Northwest's trunk line was modeled with 5-mile block valve spacing (as proposed) away from the population areas, 2.5-mile near populated areas, and also as before, with additional 1-mile block valve spacing near the population areas.

The modeling analyses were carried out and a corresponding risk assessment was performed for the Shute Creek Alternative with additional block valves. The results are shown in Table 2-15. It was found that only Calpet would be at risk of exposure to lethal levels from a trunk line rupture. The annual risk of lethal exposure at LaBarge declines to negligible. The use of additional block valves reduces the annual risk of lethal exposure at Calpet by about 23 percent (from 0.00048 to 0.00037). The annual risk of discomfort exposure at Calpet is reduced even more, about 45 percent (from 0.00093 to 0.00053) with this additional block valve spacing. The annual

TABLE 2-13

ANNUAL RISK TO POPULATED AREAS FROM PROPOSED ACTION WITH ADDITIONAL BLOCK VALVES

Populated Area	Individual Risk of Lethal Exposure[1]	Individual Annual Risk of Significant Impact[2]	Approximate Number of People (1990)[3]
LaBarge	negligible[4]	negligible	1,206
Big Piney	negligible	negligible	1,177
Marbleton	negligible	negligible	1,134
Calpet	0.00018	0.00025	54
Fontenelle Recreation Area	negligible	negligible	1,210

[1]Risk values shown in this table, such as 0.00025, mean 25 chances per 100,000.

[2]Significant exposures are those that would cause eye irritation, coughing, loss of smell, or other discomfort.

[3]Includes people in incorporated and unincorporated area.

[4]Negligible means that the modeling analysis indicates <u>no</u> risk.

TABLE 2-14

ANNUAL RISK TO POPULATED AREAS FROM BUCKHORN ALTERNATIVE WITH ADDITIONAL BLOCK VALVES

Populated Area	Individual Risk of Lethal Exposure[1]	Individual Annual Risk of Significant Impact[2]	Approximate Number of People (1990)[3]
LaBarge	negligible[4]	negligible	1,206
Big Piney	negligible	negligible	1,177
Marbleton	negligible	negligible	1,134
Calpet	0.00018	0.00025	54
Fontenelle Recreation Area	negligible	negligible	1,210

[1]Risk values shown in this table, such as 0.00025, mean 25 chances per 100,000.

[2]Significant exposures are those that would cause eye irritation, coughing, loss of smell, or other discomfort.

[3]Includes people in incorporated and unincorporated area.

[4]Negligible means that the modeling analysis indicates <u>no</u> risk.

TABLE 2-15

ANNUAL RISK TO POPULATED AREAS FROM SHUTE CREEK ALTERNATIVE WITH ADDITIONAL BLOCK VALVES

Populated Area	Individual Risk of Lethal Exposure[1]	Individual Annual Risk of Significant Impact[2]	Approximate Number of People (1990)[3]
LaBarge	negligible[4]	0.000068	864
Big Piney	negligible	negligible	861
Marbleton	negligible	negligible	845
Calpet	0.00037	0.00053	40
Fontenelle Recreation Area	negligible	negligible	1,210

[1]Risk values shown in this table, such as 0.00053, mean 53 chances per 100,000.

[2]Significant exposures are those that would cause eye irritation, coughing, loss of smell, or other discomfort.

[3]Includes people in incorporated and unincorporated area.

[4]Negligible means that the modeling analysis indicates no risk.

risk of discomfort exposure declines to negligible at Big Piney, Marbleton, and the Fontenelle Recreation Area, and declines by about 80 percent (from 0.00033 to 0.000068) at LaBarge.

NORTHERN ALTERNATIVE WITH ADDITIONAL BLOCK VALVES

For the Northern Alternative the Quasar trunk line was modeled with 10-mile block valve spacing (as proposed) away from the designated populated areas, and as before with, additional 2-mile block valve spacing near the population areas. Northwest's trunk line was modeled with 5-mile block valve spacing (as proposed) away from the population areas, 2.5-mile near populated areas, and as before, with additional 1-mile block spacing near the population areas.

The modeling analyses were carried out and a corresponding risk assessment was performed for the Northern Alternative with additional block valves. The results are shown in Table 2-16. It was found that, with these additional block valves, none of the population areas would be at annual risk of significant exposures.

EFFECTS OF ADDITIONAL BLOCK VALVES ON EXPOSURE DISTANCES

Table 2-17 shows the effects of additional block valves on the downwind distances for significant H_2S exposure from trunk line ruptures. Exposure distances would depend not only on block valve spacing but also on pipeline diameter and atmospheric conditions. These parameters are summarized for all trunk lines (30 inches and larger) for each applicant and alternative.

CONCLUSION

Use of additional block valves along trunk line segments near population areas can appreciably reduce the risk of significant impacts from the Proposed or Alternative Actions:

- The small community of Calpet is expected to experience an appreciably smaller risk of lethal exposure under the Proposed Action, Buckhorn Alternative, or Shute Creek Alternative. It is expected that none of the other population areas would experience an annual risk of lethal dose.

- Under either the Proposed Action, the Buckhorn Alternative, or the Shute Creek Alternative the risks of discomfort exposure at LaBarge, Big Piney/Marbleton, and the Fontenelle Recreation Area are reduced effectively to zero (except for LaBarge under the Shute Creek Alternative).

- Under the Northern Alternative, no risks of significant exposures are expected at any of the population areas.

Effects on Wildlife and Livestock

Potential impacts of sour gas ruptures or leaks on wildlife and livestock are related to analyses performed for human health and safety. Potential for a rupture or leak along any particular segment of the gathering lines or trunk lines is very small. Because of the mobility of wildlife populations, and to a lesser extent livestock herds, the probability of effects to

TABLE 2-16

ANNUAL RISK TO POPULATED AREAS FROM NORTHERN ALTERNATIVE WITH ADDITIONAL BLOCK VALVES

Populated Area	Individual Risk of Lethal Exposure	Individual Annual Risk of Significant Impact[1]	Approximate Number of People (1990)[2]
LaBarge	negligible[4]	negligible	1,212
Big Piney	negligible	negligible	1,217
Marbleton	negligible	negligible	1,171
Calpet	negligible	negligible	56
Fontenelle Recreation Area	negligible	negligible	1,210

[1]Significant exposures are those that would cause eye irritation, coughing, loss of smell, or other discomfort.

[2]Includes people in incorporated and unincorporated area.

[3]Negligible means that the modeling analysis indicates <u>no</u> risk.

TABLE 2-17

DOWNWIND DISTANCES FOR SIGNIFICANT H_2S EXPOSURES FROM RUPTURES OF PROPOSED TRUNK LINES

Applicant	Trunk Line Diameter (inches)	Block Valve Spacing (miles)	Downwind Distance for Lethal Dose (miles)		
			Stable Atmosphere	Neutral Atmosphere	Unstable Atmosphere
Quasar (Proposed Action) and Exxon (Shute Creek Alternative)	30	10	2.5	0.9	0.4
	30	2[1]	1.7	0.8	0.4
Quasar (Buckhorn, Shute Creek, and Northern Alternatives)	36	10	3.5	1.2	0.6
	36	2[1]	2.1	1.1	0.4
Northwest (All Alternatives)	30	5	2.9	1.1	0.5
	30	2.5	2.2	0.9	0.4
	30	1[1]	1.6	0.8	0.3
			Downwind Distance for Significant Dose (miles)		
Quasar (Proposed Action) and Exxon (Shute Creek Alternative)	30	10	6.8	1.4	0.7
	30	2[1]	2.5	1.2	0.4
Quasar (Buckhorn, Shute Creek, and Northern Alternatives)	36	10	9.9	1.9	0.8
	36	2[1]	3.2	1.6	0.6
Northwest (All Alternatives)	30	5	5.6	1.7	0.7
	30	2.5	3.4	1.5	0.6
	30	1[1]	2.2	1.2	0.4

[1]Mitigation block valve spacing.

wildlife cannot be assessed. If a rupture occurred within a wildlife or livestock concentration area during a period of year and time of day when wildlife or livestock were concentrated near the rupture, and rupture and meteorological conditions were both the worst possible case, many (but an unknown number of) animals could be lost. Such a possibility does exist, but probabilities are extremely low and potential wildlife and livestock impacts are not considered significant.

METHODOLOGIES

INTRODUCTION

The purpose of this chapter is to describe the methodologies applied to quantify the health and safety impacts of the proposed Riley Ridge Project. To quantify these impacts requires (1) an estimate of the probability of an accident, (2) a description of the possible dose patterns, (3) the probability that a worst-case dose pattern would occur (which is primarily a function of weather), and finally (4) a relationship between individual dose patterns and the distribution of individuals likely to be exposed.

The first step in the analysis is to review the past accident statistics for well field blowouts and pipeline ruptures. These historical data are then used to quantify the probability of accidents for the proposed project. A Poisson statistical distribution is used for this purpose.

The second step is to quantify the H_2S concentrations (or dose patterns) that might occur in the event of an accident. These patterns are a function of both engineering design and weather conditions. Dose patterns are developed using air quality dispersion models. Analysis results have been presented in Chapter 2, Environmental Consequences. They are also described in this chapter in order to show their relationship to the remaining steps in the assessment methodology.

The third step is to quantify, where appropriate, the probability that the worst-case dose pattern would occur. Finally the population distribution in the study area is compared to the exposure risk areas.

The major assumptions made in quantifying health and safety impacts are:

- Historical data for well blowouts and pipeline ruptures are statistically meaningful.

- Past accident frequencies can be related to future accident frequencies. Because these accidents are rare events, they may be described through a statistical relationship called a Poisson distribution.

- The gas released from a well blowout during drilling is assigned a 50 percent probability of full plume rise (as calculated by the model), and an equal probability of rising only (nominally) 5 meters, before dispersing downwind. These probabilities are arbitrary, but are assigned to reflect the fact that during drilling the presence of the drilling equipment, BOPs, etc., would be about as likely to inhibit full plume rise as to permit it.

- The gas released from a well blowout <u>during production</u> is assigned an 80 percent probability of full plume rise (as calculated by the model), and a 20 percent probability of rising only (nominally) 5 meters, before dispersing downwind. These probabilities reflect the fact that during production there are fewer, but nevertheless some, impediments to full plume rise.

- The gas release from a small pipeline is assigned a 50 percent probability of full plume rise (as calculated by the model), and an equal probability of rising only (nominally) 20 meters, before dispersing downwind. These probabilities reflect the fact that a pipe can rupture in any of a number of different ways, some of which lead to maximum plume rise, and some of which (e.g., a downward-directed rupture) lead to much shallower plume rises.

- The gas released from a large pipeline is assigned a 50 percent probability of full plume rise, and an equal probability of rising only (nominally) 50 meters. The rationale is the same as that presented above. (The larger partial plume rise corresponds to the larger momentum flux associated with ruptures of bigger pipes.)

- The models used to estimate dose patterns cannot yield precise estimates, but are sufficiently accurate to address the relative risks of various project components and the relative risks of component alternatives, and to suggest locations where additional safety measures might be appropriate.

<u>PROBABILITY OF AN ACCIDENT</u>

WELL BLOWOUTS: HISTORICAL DATA

Table 3-1 presents a summary of data on well field blowouts. Data from the Texas Railroad Commission show that for natural gas drilling operations in Texas the blowout rate for 1977 to 1981 was 0.0037, or 1 blowout per 270 wells drilled. The blowout rate for producing wells was 0.000051, or 1 blowout per 20,000 producing well-years.

Data from the Province of Alberta, Canada (1970 to 1980) reveal blowout rates of 0.0016, or 1 per 630 gas wells drilled, and 0.00036, or 1 blowout per 3,000 producing well-years. A suggested reason for the lower blowout rates during drilling in Alberta is that the vast majority of wells drilled in Alberta contain sour gas and, therefore, extra precautions are taken during drilling.

The data for Alberta and Texas show, however, that over the life of the well (assuming 30 producing years) blowout rates are very similar for drilling and production combined.

A third source, the U.S. Geological Survey (U.S. Army Corps of Engineers 1982) indicates that for the period 1969 through 1981, 1 blowout occurred per 250 exploratory and development wells drilled on the outer shelf of the Gulf of Mexico. The majority of the blowouts were of short duration (typically three days). This document also reports that blowouts are more frequent during drilling operations than during production.

TABLE 3-1

WELL FIELD BLOWOUT RATES

Source	Blowouts/ Wells Drilled	Blowouts/ Producing Well-Year
Texas[1]	1 per 270	1 per 20,000
Alberta, Canada[2]	1 per 630	1 per 3,000
Gulf of Mexico[3]	1 per 250	Not given

Note: A blowout is defined as any uncontrolled release of gas to the atmosphere. The average length of a blowout is three days.

[1]Texas data for years 1977-1981 from David W. Layton, Lawrence Livermore National Laboratory, Livermore, California, October 4, 1982. Blowouts per wells drilled includes dry holes.

[2]Alberta, Canada, data for years 1970-1980 from David W. Layton, Lawrence Livermore Laboratory, Livermore, California, October 4, 1982. Blowouts per wells drilled includes dry holes.

[3]Production of Natural Gas from the Lower Mobile Bay Field, Alabama, Final Environmental Impact Statement, U.S. Army Corps of Engineers, 1982. For Gulf of Mexico data.

The data shown in Table 3-1 suggest that a blowout rate for development wells of 1 per 630 wells drilled provides a realistic estimate for the probability of sour gas well blowouts. Similarly, a blowout rate of 1 per 3,000 producing well-years would also yield representative results.

PIPELINE RUPTURES: HISTORICAL DATA

Historic information on pipeline failures, collected from numerous sources is summarized in Table 3-2. This table shows that there is a substantial range in the rate of pipeline incidents, depending upon location and product carried. The following paragraphs provide additional information about the sources for these data.

The U.S. Department of Transportation, Office of Pipeline Safety Operations (OPSO), collects statistics on service failures, leaks, or ruptures (incidents) in natural gas transmission and gathering lines. Commencing on February 9, 1979, all natural gas transmission companies have been required to notify OPSO in the event of a "reportable" incident, as defined in the Code of Federal Regulations (CFR), Title 149, Part 191. Reportable incidents are defined by OPSO as those which:

- Resulted in death or injury requiring hospitalization;
- Required the removal from service of any segment of transmission pipeline;
- Resulted in ignition;
- Caused $5,000 or more in damage;
- Involved a leak requiring immediate repair; or
- In the judgement of the operator was significant even though it did not meet the above criteria.

In the ten-year period from 1970 to 1979 inclusive, there were 5,823 reportable incidents during 2,810,934 operational pipeline miles-years (transmission and gathering lines) (Jossi 1982). This translates to an incident rate for U.S. natural gas transmission and gathering pipeline of 0.0021 incidents per mile-year (during the period 1970-1979).

The Texas Railroad Commission also maintains information on natural gas incidents (defined as incidents involving damage greater than $1,000 or injuries resulting in hospitalization or death). In fiscal 1980 and 1981 there were approximately 370 incidents during 340,000 operational natural gas pipeline miles, or 0.0011 incidents per mile-year (Hollub 1982).

Data are also available from the U.S. Department of Energy for Class A and B natural gas pipelines for the years 1971 through 1980. The total number of failures for transmission and gathering systems during that time was 400, for a failure rate of 0.0019 failures per mile-year (U.S. Army Corps of Engineers 1982).

TABLE 3-2

GAS PIPELINE INCIDENT RATES

Source	Type of Product	Accident Rate (Incident/Mile-Year)
U.S. Dept. of Transportation (Office of Pipeline Safety)[1]	Natural Gas	0.0021 (gathering & transmission lines)
Texas Railroad Commission[2]	Natural Gas	0.00112 (fiscal 1981) 0.00108 (fiscal 1982) 0.0011 (fiscal 1982)
Production of Natural Gas Lower Mobile Bay Field, Alabama[3]	Natural Gas	0.0019
Energy Resources Conservation Board Alberta, Canada[4]	Sour Gas Natural Gas	0.00022 0.0041

[1]David Jossi, Information Systems Division, Research and Special Programs Administration, U.S. DOT, 1982.

[2]Sonny Hollub, Texas Railroad Commission, 1982.

[3]Production of Natural Gas From the Lower Mobile Bay Field, Alabama, FEIS, U.S. Army Corps of Engineers, May 1982.

[4]Wendy E. Roberts, Energy Resources Conservation Board, Calgary, Alberta, Canada, 1982.

Although the information available for U.S. sources does not address incidents for sour gas pipelines (data cited previously was for natural gas pipelines in general), such data are available from the province of Alberta, Canada, one of the largest sour gas producing areas in the world. Most of the natural gas extracted in Alberta contains H_2S, and many of the wells contain in excess of 50 percent H_2S (Roberts and Cameron 1982, personal communication). Experience in developing and transporting sour gas during the previous decade in Alberta has shown that the failure rate for pipelines transporting gas containing H_2S is approximately 0.0002 incidents per mile-year. One possible reason for Alberta's much lower incident rate for sour gas pipeline failures (relative to natural gas pipeline failures in the U.S) is that greater care and additional precautions may be taken in protecting the sour gas pipes (Roberts and Cameron 1982, personal communication).

From the available information it appears appropriate to assume that pipeline incidence rates fall somewhere in the range of 0.0002 to 0.002 incidents/mile-year. However, most incidents do not lead to complete pipe failure, so additional information is needed to estimate the percentage of incidents that <u>could</u> result in complete rupture. The next several paragraphs discuss the available historical statistics on causes and modes of pipe incidents.

One such useful set of available pipeline data is that collected over the period 1971-1980 by the U.S. Army Corps of Engineers for the Lower Mobile Bay Field in Alabama. These data, summarized in Table 3-3, show that outside force is by far the largest single cause of pipeline incidents. As shown, 53 percent of incidents were due to outside force, 23 percent to construction or material defect, 17 percent to corrosion, and 7 percent to other factors (U.S. Army Corps of Engineers 1982).

Another set of pipeline incident data is available from the American Gas Association. Again the major cause of service incidents is outside force, which accounts for 55.5 percent. Material damage accounts for 15.8 percent, and corrosion accounts for 15.6 percent. (American Gas Association 1980). The largest fraction of outside force incidents result from equipment operated by outside parties. For the period 1970 through 1978 the major components of outside force incidents were (American Gas Association 1980):

- equipment operated by outside party, 69.3 percent;
- earth movement, 13.0 percent;
- equipment operated by or for pipeline operator, 6.8 percent;
- weather, 4.1 percent;
- vehicle, 1.6 percent;
- willful damage, 1.0 percent; and
- other causes; 3.9 percent.

TABLE 3-3

TRANSMISSION AND GATHERING SYSTEMS INCIDENT FREQUENCY BY CAUSE OF INCIDENT FOR 1971 - 1980

Cause	Ten-Year Total of Incidents	Incidents/ Mile-Year[1]
Corrosion	808	0.00039
Damage by Outside Forces	2,491	0.00120
Construction Defect or Material Failure	1,055	0.00051
Other	311	0.00015
TOTAL	4,665	0.00230

Source: U.S. Department of Transportation 1971 - 1980. From Production of Natural Gas From Lower Mobile Bay Field Alabama, Final Environmental Impact Statement, U.S. Corps of Engineers, May 1982

[1]Based on 205,663 miles of transmission and gathering lines (average 1971 - 1980)

The data also show an increase of incident frequency with pipeline age. This is likely to be so for several reasons. First, corrosion incidents are more frequent in older pipe because corrosion is time dependent. Second, there is a higher frequency of outside incidents in older pipe, perhaps because (as research has shown) thinner pipe is more easily damaged by outside force, and also because older lines are generally smaller in diameter, have thinner walls, and are thus more likely to suffer outside force damage. Additionally, older pipes are less well marked than newer larger lines and are thus more prone to outside force damage.

Research undertaken by de la Mare and Anderson (de la Mare 1980) and displayed in Figure 3-1, show that pipeline failure rates diminish with increasing diameter size for natural gas pipelines. Table 3-4 also suggests a steady decline in failures per mile as diameter size increases. Pipeline of less than 6 inches in diameter accounts for the largest number of accidents, 40 percent. It is suggested that this correlation is due to the vulnerability of small diameter pipe to outside force.

A report prepared by the American Gas Association (1980) addresses the issue of the extent of ruptures and leak sizes. From U.S. DOT data from 1970 through 1978 on reportable incidents for natural gas transmission and gathering lines, it was found that there are essentially ten identifiable categories of pipeline incidents. These categories are:

1) Propagating Ruptures - Service incidents classified as ruptures in which a defect or crack developed and propagated for more than 1 foot along the axis of the pipe.

2) Punctures, Blowouts, or Tears - Service incidents classified as ruptures in which a longitudinal or circumferential opening or crack developed but which was limited to 1 foot or less.

3) Service incidents classified as ruptures in which the extent of propagation, if any, was not given or was given as zero, and for which no origin was given.

4) Service incidents classified as ruptures in which the extent of propagation, if any, was not given or was given as zero, and in which a failure of a tap was indicated.

5) Service incidents classified as systems in which the extent of propagation, if any, was not given or was given as zero, and in which a failure of a non-piping component was indicated.

6) Service incidents classified as leaks but in which some pipe was replaced and the stress level exceeded 20 percent of specified minimum yield strength (SMYS).

7) Service incidents classified as leaks but in which some pipe was replaced and the stress level did not exceed 20 percent of SMYS.

8) Service incidents classified as leaks where no pipe was replaced.

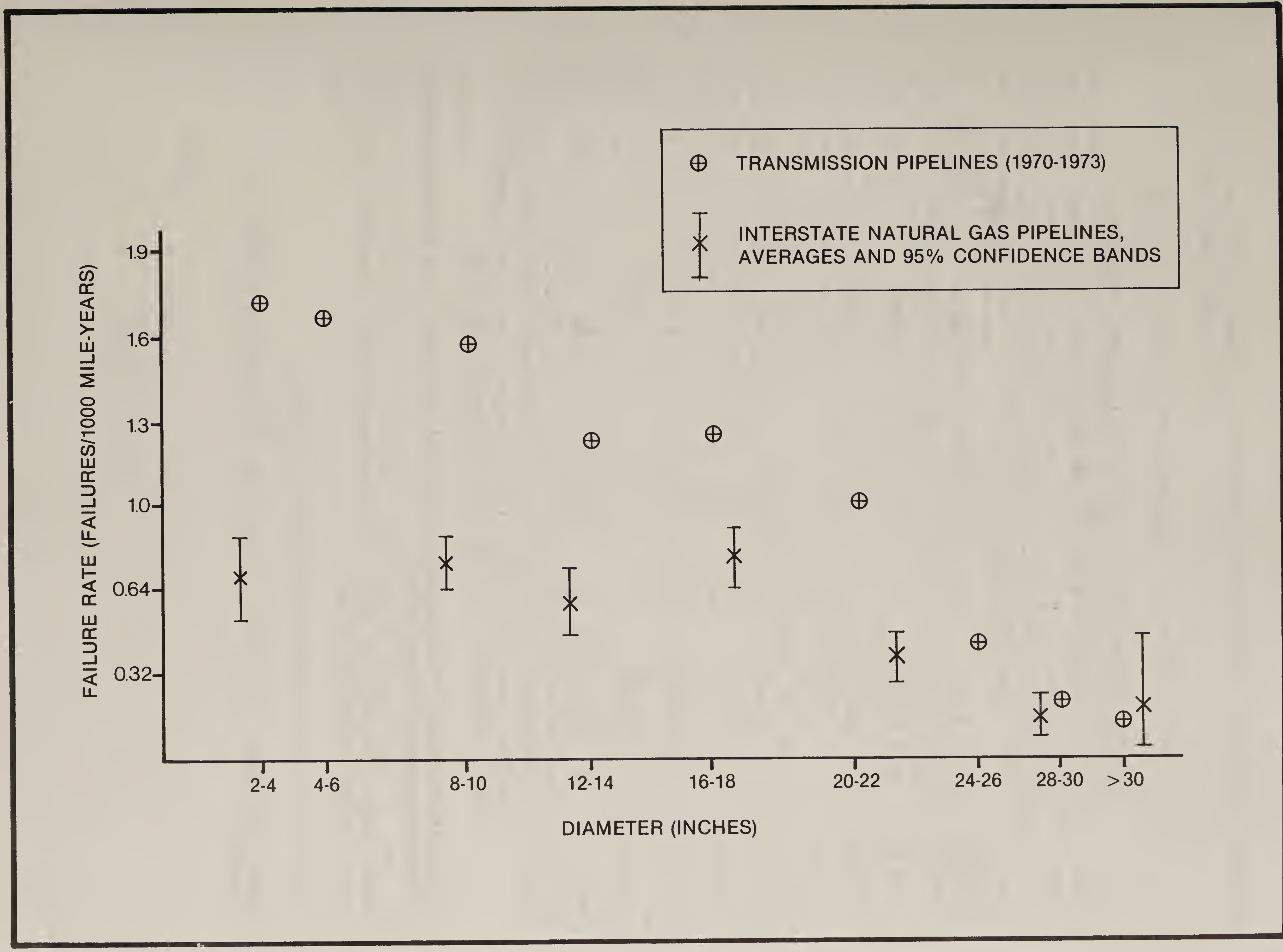


FIGURE 3-1 PIPELINE RELIABILITY

TABLE 3-4

AVERAGE TRANSMISSION LINE PIPE MILEAGE AND INCIDENTS BY PIPE DIAMETER FOR 1971 - 1979

Line Pipe Diameter (inches)	Line Pipe Length [1,2] Miles	Line Pipe Length [1,2] Percent of Total	Incident Number[3]	Incident Percent of Total
0-5	19,311	12	1,756[4]	44
5.1-10	22,481	14	814	20
10.1-15	13,201	8	410	10
15.1-20	27,776	17	612	16
20.1-25	23,157	14	216	5
25.1-30	44,005	27	150	4
>30	13,170	8	33	1
TOTAL	163,101	100	3,991	100

Source: U.S. Department of Energy. 1980. From Production of Natural Gas From the Lower Mobile Bay Field, Alabama, Final Environmental Impact Statement, U.S. Corps of Engineers, May 1982.

[1]1979 mileage data. Mileage increased by 17,000 miles over 10-year period. Percentage changed only slightly.

[2]Transmission line mileage only. Mileage average used in report is 205,663, which included gathering lines.

[3]Data are for transmission and gathering systems.

[4]Number represents incidents for pipelines or less than 6 inches in diameter.

9) Service incidents classified as leaks where a non-piping component was involved.

10) Service incidents classified as leaks where a tap connection was involved.

As shown in Table 3-5, the first two categories, classified as large ruptures, accounted for only 11 percent of all incidents from 1970-1978. The first five categories (ruptures of any size) accounted for approximately 34 percent of all reported incidents. The report noted, however, that ruptures have a tendency to propagate as stress levels increase.

On the basis of the evidence previously provided, it can be concluded that pipeline incident rates per mile-year for natural gas pipeline are generally on the order of 0.0002 to 0.002. In addition, evidence suggests that the probability of an incident decreases with size, varying from 0.001 for a 6-inch line, to 0.0001 for a 30-inch line (U.S. DOT data for 1970-1973), and also increases with age. Further, only 7 to 11 percent of all pipeline incidents can be conclusively classified as large ruptures.

In the interest of providing conservative estimates of health and safety impacts, a rupture probability of 0.0002 ruptures per mile-year will be utilized in the impact assessment. This value is consistent with U.S. DOT experience, because 0.11 ruptures per incident (that is, 11 percent) x 0.0021 incidents per mile year = 0.00023 <u>ruptures</u> per mile year. It is also <u>conservative</u> relative to the Alberta sour gas pipeline data, because that <u>data indicates</u> a <u>total</u> incident rate of 0.00022 incidents per mile-year (see Table 3-2) and <u>only</u> a small fraction of these are likely to have been pipeline <u>ruptures</u>. Because the anticipated pipeline rupture rate for the Riley Ridge Project might be expected to be much closer to the Alberta historical data than to the Alabama (Lower Mobile Bay) data, the choice of 0.0002 ruptures per mile year is considered quite conservative for the risk assessment.

PROBABILITY OF AN ACCIDENT: RILEY RIDGE PROJECT

Forecasts of well blowouts or pipeline ruptures have been made based on a probability distribution of the number of blowouts or ruptures that might occur during the project lifetime. The basic assumption is that the occurrence of rare events (blowouts or ruptures) is described by a Poisson process.

$$P(n) = \frac{e^{-\lambda t}(\lambda t)^n}{n!} \tag{3-1}$$

Where:

n	=	Number of accidents
λ	=	Occurrence rate per unit exposure
t	=	Exposure variable

TABLE 3-5

PIPELINE INCIDENTS BY CATEGORY

Type	Number	Percent
1	256	7.3
2	122	3.5
3	565	16.0
4	56	1.6
5	199	5.6
6	333	9.4
7	431	12.2
8	651	18.4
9	690	19.5
10	154	4.4
Unclassified cases	76	2.2
TOTAL	3,533	100.1
Missing cases	76	
No. service incidents	3,609	

Source: American Gas Association. September 1980. An Analysis of Reportable Incidents for Natural Gas Transmission and Gathering Lines 1970 through 1978.

The "exposure variable" is a quantity which has a statistical relationship to the occurrence of an event. For example, for the Riley Ridge Project an exposure variable might be the volume of gas produced, or the number of wells drilled, or the miles of pipeline in service.

As described in the previous sections that review historical accident frequency data, the exposure variables most appropriate to this study are:

1) Number of wells drilled;

2) Producing well-years;

3) Mile-years of pipeline.

Although historical information suggests that exposure variables for pipelines might include pipeline diameter and age, the data base was insufficient to identify reliable occurrence rates (λ).

The occurrence rates selected for use in this study are:

1) 1 blowout per 630 wells drilled (following the Alberta, Canada experience);

2) 1 blowout per 3,000 producing well-years;

3) 1 rupture per 5,000 pipeline mile-years.

These rates are assumed to account for the engineering and safety precautions exercised in sour gas well fields and transportation systems.

Equation 3-1 is appropriate for estimating the probability of a specific number of accidents occurring. The expectation value of the Poisson distribution is:

$$E = \lambda t \qquad (3\text{-}2)$$

and the probability of one or more accidents occurring is given by:

$$P(n \geq 1) = 1 - e^{-\lambda t} \qquad (3\text{-}3)$$

An illustration of the use of these equations is provided in Table 3-6. Production well blowouts are used in the example. As shown, there is an expectation that with 240 wells producing over 30 years that 2.4 blowouts would occur. The probability of only one blowout occurring is 22 percent but the probability of one or more blowouts is 91 percent.

DOSE ASSESSMENT METHODOLOGY

WELL BLOWOUTS

This section presents the methods and model inputs used to predict H_2S concentration profiles downwind of a well blowout. Following these discussions, the results of the modeling are presented along with a comparison of the model predictions to actual concentrations measured during a well blowout in the Riley Ridge area.

TABLE 3-6

BLOWOUT FREQUENCY DURING THE PRODUCTION LIFETIME (30 YEARS) OF THE WELL FIELD

Historical Blowout Rate	1 per 3,000 Producing Well-years
Well field expectation per year	0.08
Well field expectation over 30 years	2.40
Probability that any specific well will blow out during its producing lifetime[1]	0.01
Probability of one blowout occurring during producing lifetime of the project[1]	0.22
Probability of one or more blowouts occurring during producing lifetime of the project[1]	0.91

[1]Assumes 240 producing wells

Technical Discussion

When a gas under high pressure suddenly exits a pipeline or well bore, the high pressure jet may exit with supersonic velocity but will rapidly come to equilibrium with the ambient pressure. If the jet is perturbed by obstructions such as the blowout preventers or other drilling apparatus, the rise of the gas would be restricted. However, if the jet has a clear path above it, then the rise could be substantial. To estimate the full plume rise the jet diameter, vertical velocity, and volumetric flow rate are calculated at the point where compressibility effects become negligible.

These parameters are then used in standard plume dispersion models that apply Briggs' plume rise algorithms (Briggs 1975). This section discusses the detailed procedures for estimating the equilibrium characteristics of the supersonic jet, as presented in Wilson 1981a.

To estimate plume rise and effective plume parameters for a well blowout, the gas exit pressure, P_o, is computed as follows:

$$P_o = \frac{m_o}{A_o} \sqrt{\frac{2RT_o}{k(k+1)}} \qquad (3\text{-}4)$$

Where:

m_o = Mass flow rate
A_o = Cross-sectional area at exit
R = Gas constant for escaping gas
k = Ratio of specific heats
T_o = Pipe stagnation temperature

For any pressure P the jet Mach number M is given by:

$$M = \phi \left[1-\left(\frac{k-1}{2}\right)\phi^2\right]^{-\frac{1}{2}} \qquad (3\text{-}5)$$

Where

$$\phi = \left[(k+1)\frac{P}{P_a} - 1\right] / k\sqrt{\frac{k+1}{2}\frac{P}{P_a}} \qquad (3\text{-}6)$$

And

P_a = Ambient Pressure

The "effective" area of the jet, A, at the height corresponding to this Mach number is calculated from:

$$A = \left[A_o(1+k)\frac{P}{P_a} - 1\right] / kM^2 \qquad (3\text{-}7)$$

and thus, the "effective" radius r of the jet is:

$$r = (A/\pi)^{\frac{1}{2}} \tag{3-8}$$

The Mach number at the source exit, M_s, is calculated from (3-5) and (3-6) for $P=p_o$. The corresponding effective area and effective radius of the jet at exit are A_s and r_s, respectively, as calculated from (3-7) and (3-8).

Compressibility effects become negligible at the height for which the Mach number of the jet decreases to ~0.3 (Wilson 1981a). The effective plume characteristics at this height are given by:

$$r_{eff} = \frac{M_s}{0.3} r_s \tag{3-9}$$

$$z_{eff} = \frac{r_{eff} - r_s}{2\alpha} \tag{3-9}$$

$$\rho_{eff} = P_a/RT_o \tag{3-11}$$

$$V_{eff} = \frac{M_o}{\rho_{eff}} \tag{3-12}$$

Where:

r_{eff} = radius of the jet at Mach number (=0.3) for which compressibility effects become negligible

z_{eff} = height of jet at this point

α = entrainment factor

ρ_{eff} = effective plume density at this point

V_{eff} = effective volumetric flow rate at this point

Thus, if the initial jet is supersonic, the plume can be modeled in the same manner as any other momentum-driven point source, except that the "stack parameters" are first modified as follows:

- The "physical stack height" of the source is replaced by the height z_{eff}
- The "stack diameter" is replaced by r_{eff}
- The "volumetric flow rate" is replaced by V_{eff}

In this study the effective stack parameters were input to the Environmental Protection Agency's COMPLEX II air quality model. COMPLEX II is a standard bivariate Gaussian dispersion model which uses Briggs' plume rise equations and the Pasquill-Gifford stability classes and dispersion coefficients. The model was run for flat terrain receptors at distances of 50 to 100,000 meters directly downwind of the blowout, for each of the simulated meterological conditions described below. Each meteorological condition was modeled with each of two assumptions regarding plume rise: 1) plume rise as calculated using Briggs' formula and the effective stack parameters, and 2) minimum plume rise of a nominal 5 meters.

Meteorology and Dispersion

A wide range of meteorological scenarios was evaluated for the well blowouts. The conditions selected are representative of extreme daytime instability with light winds, slightly unstable conditions with moderate winds, neutral atmospheric conditions with moderate and high wind speeds (the most typical scenario for the region), and nighttime stable regimes with light winds. These scenarios provide a range of predicted H_2S impacts throughout the spectrum of feasible meteorological and dispersive conditions. Certain conditions will result in the maximum predicted concentrations in close to the blowout, while other conditions result in the peak impacts at large distances. The stability class/wind speed scenarios modeled include; 1) very unstable, 2 meters/second, 2) slightly unstable, 7 meters/second, 3) neutral, 5 meters/second, 4) neutral, 10 meters/second, and 5) stable, 2-3 meters/second.

Model Input Parameters

The parameters used in the investigation of well blowouts are presented in Table 3-7. A single generic well was modeled because of the similarity of the applicants' well parameters. The flow rate applied is based on Exxon's estimate of the upper limit under actual blowout conditions, which considers damage to pipes, valves, or other mechanical devices which restrict the flow. The flow rate and H_2S percentage are used to calculate the emission rate, while the remaining inputs are primarily used to calculate the height at which compressibility effects are negligible so that the Brigg's plume rise formula can be used. To bound the predicted concentrations, cases were modeled with (1) nominal 5-meter plume rise as well as with (2) the model-calculated plume rise.

The effective calculated stack parameters used in the modeling with COMPLEX II are listed in Table 3-8.

Dose Sensitivity Analysis

This section presents a dose sensitivity analysis of the well blowout modeling. Doses are discussed for the case of full, undisturbed plume rise based on the Brigg's plume rise formula, and for a nominal 5-meter plume rise case. All H_2S concentrations are presented for a direction directly downwind of the blowout, and as such, are representative of the highest ground level concentrations at any given distance from the well.

TABLE 3-7

INPUTS TO THE WELL BLOWOUT ANALYSIS

Parameter	Value
Flow Rate	125×10^6 ft^3/day[1]
Percent H_2S	3.2 to 4.5 percent
Gas Constant	2.27×10^6 cm^2/s^2k
Specific Heat Ratio at 150°F, 2,200 psi	3.5
Pipe Diameter	3.5 inch
Ambient Pressure	780 mb
Ambient Temperature	37°F
Pipe Stagnation Temperature	150°F

[1]The uncontrolled flow rate during a blowout would be in excess of 20MMCFD. The theoretical limit is estimated to be 250 MMCFD.

TABLE 3-8

EFFECTIVE STACK PARAMETERS FOR THE WELL BLOWOUT DISPERSION MODELING

Parameter	Value
Effective Stack Height	3.6 meters
Effective Stack Diameter	1.64 meters
Effective Exit Velocity	23.8 meters/second
Exit Temperature	339°K
H_2S Emissions Rate[1]	1,530-2,150 g/s

[1]Assumes a gas flow rate of 125 MMCFD with an H_2S content of 3.2 percent to 4.5 percent.

Figure 3-2 presents downwind profiles of one-hour average H_2S concentrations assuming full plume rise. Only results for 3.2 percent H_2S content are shown. The profiles show the highest concentrations within 1 kilometer of the blowout occur during moderate to high wind speed conditions. Light wind speed stable conditions result in the highest concentrations beyond 2 kilometers. The calculated plume rise ranges from 25 meters for 10 meters/second wind speed and neutral stability, to 115 meters for a 2 meters/second wind speed and extremely unstable stability. None of the concentrations are above the significance criteria specified in Chapter 2.

Figure 3-3 presents the worst-case, one-hour average H_2S concentration profile assuming minimum plume rise. For the minimum plume rise case, stable light wind speed conditions result in the highest concentrations, and thus only profiles for stable 2 and 3 meters/second conditions are shown.

Because stable conditions occur frequently at night in the study region, and because a typical blowout is expected to last for up to three days, it has been assumed that these meteorological conditions have 100 percent probability of occurring during a blowout.

As shown in Figure 3-3, a 15-minute average H_2S concentration in excess of 100 parts/million could occur out to a distance of 2 to 3.5 kilometers. Individuals exposed to this level of H_2S could experience some discomfort.

Instantaneous H_2S concentrations can be estimated from COMPLEX II model results by assuming that instantaneous values are twice the 10-minute to 1-hour values. Based on this assumption, Figure 3-3 shows that lethal instantaneous doses (1,000 parts/million) might be experienced by individuals located within 0.5 to 1 kilometer of a blowout.

Comparison with the American Quasar Well #10-14 Blowout

On June 21, 1981, a blowout occurred at American Quasar's Riley Ridge #10-14 well, located approximately 15 miles west-southwest of Big Piney, Wyoming. Although the volume of gas released can only be approximated, estimates range from 5 to 100 million cfd. The gas was 3 to 4 percent H_2S. The "Report of Environmental Effects of H_2S Well Blowout", (Chris Hanson, Environmental Scientist, Rock Springs District) documents the effects of the blowout and provides a summary of actual H_2S monitoring data during the event.

The documentation of the blowout indicates that there was no damage to surrounding vegetation. No ill effects were noted at the closest residence to the blowout, located 3 kilometers to the northeast. Two ranchers in the immediate area, one of whom had cattle within a mile of the blowout, said there were no losses or ill effects to any cattle, but some large animals (four antelope and one moose), were found dead in a draw downhill and approximately 0.6 kilometer downwind from the blowout. The highest recorded H_2S concentrations at two stationary monitoring sites located 3 and 8 kilometers downwind of the well site were 20 and 2 parts/million, respectively.

The highest monitored values at the stationary sites are well within the range of predicted concentrations. The monitoring data suggest that the nominal 5-meter plume rise modeling case may overpredict worst-case

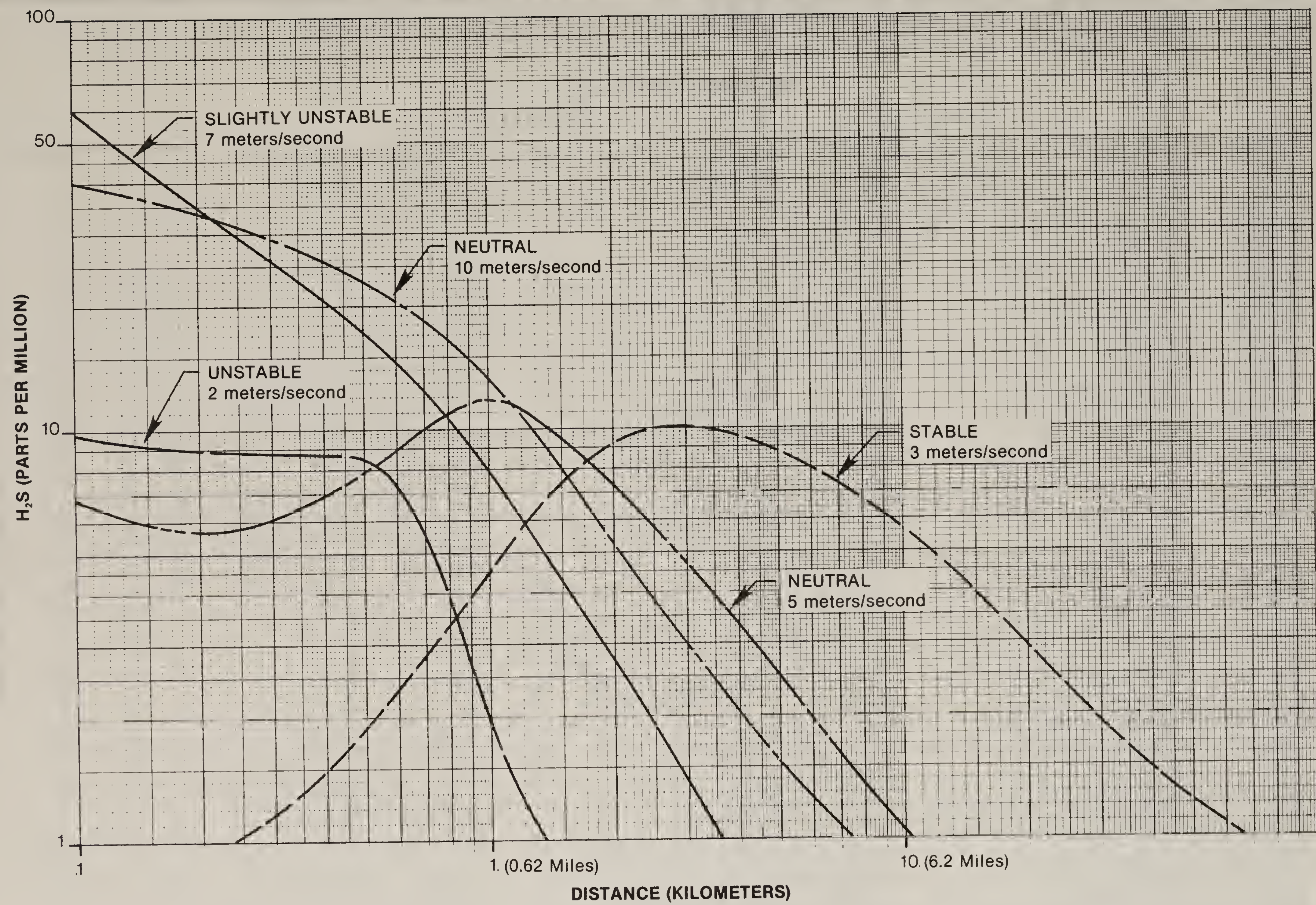


FIGURE 3-2 DOWNWIND PROFILE OF 1-HOUR AVERAGE H_2S CONCENTRATIONS (FULL PLUME RISE)

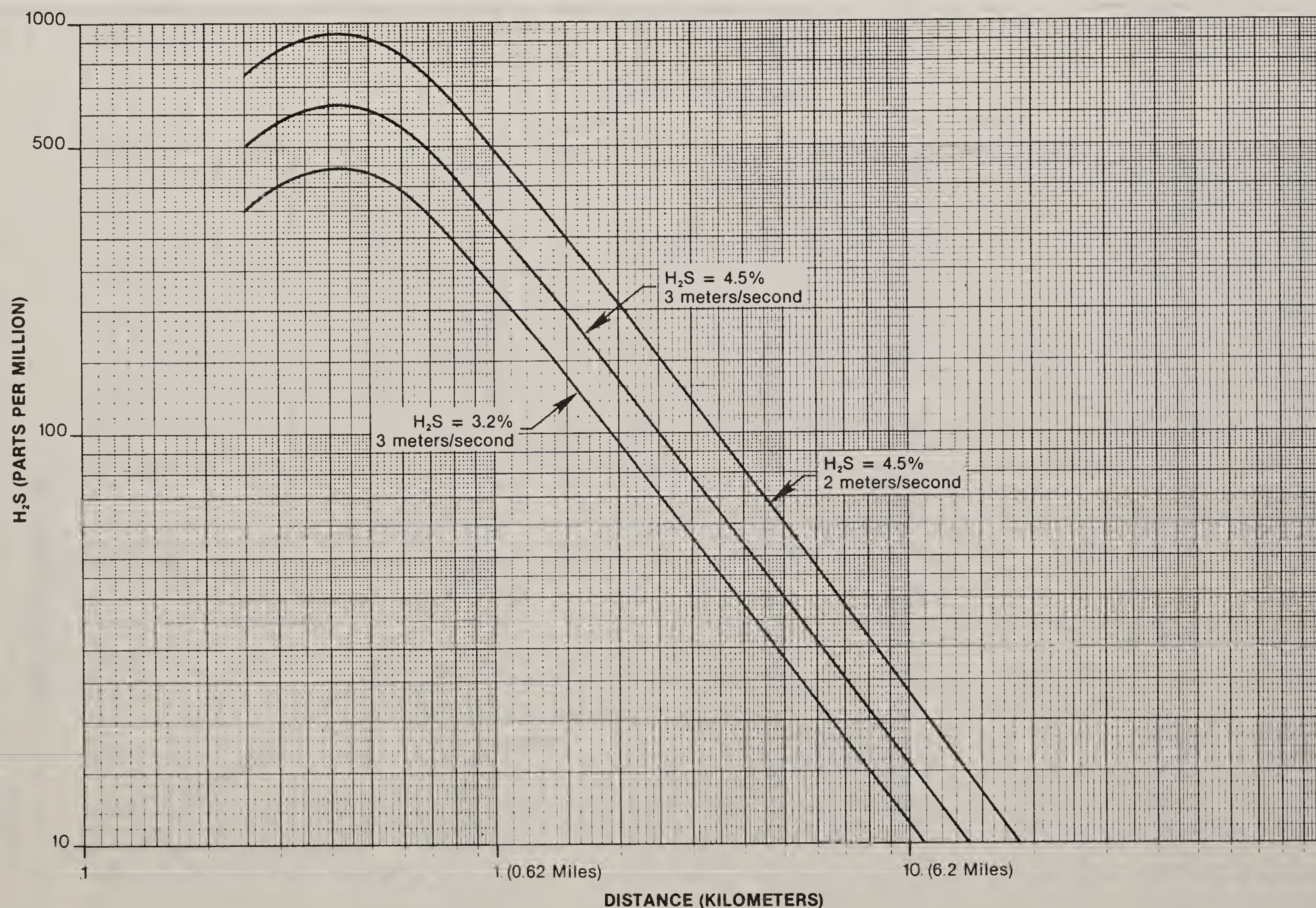


FIGURE 3-3 DOWNWIND PROFILE OF WORST-CASE 10 MINUTE TO 1-HOUR AVERAGE H_2S CONCENTRATIONS DURING STABLE CONDITIONS. (NOMINAL 5-METER PLUME RISE)

concentrations by a factor of 3 to 4. However, the predicted versus observed comparison is highly sensitive to wind direction, and it is also possible that centerline impacts during stable and light wind speed conditions never occurred at the monitoring sites.

In addition to the stationary monitors, one mobile monitoring station was used to measure H_2S at 15 random sites daily. The concentrations measured at a distance of 1 mile from the blowout were generally in the range of 100 to 300 parts/million, but a value as high as 6,500 parts/million was recorded. The 100 to 300 parts/million concentration range at 1 mile downwind is slightly higher than that predicted by the model assuming a 5-meter nominal plume rise and stable light wind speed conditions.

PIPELINE RUPTURES

Technical Discussion

Mass Release Rate

When a high-pressure gas pipeline ruptures, the gas first escapes at supersonic velocities. Block valves (if present upstream and downstream of the ruptured segment) close, and the remainder of the gas escapes at ever-decreasing velocities. Recent studies (Wilson 1979, 1981a) suggest that the mass release rate (the "blowout profile") is best simulated by a double exponential expression of the form:

$$\dot{m}_e = A_1 \left(\dot{m}_{oe} e^{-t/\tau_1} + (W_o/\tau_2) e^{-t/\tau_2} \right) \qquad (3\text{-}13)$$

Where

$\dot{m}_e$ = Mass release rate as a function of time t (kg/s)

$\dot{m}_{oe}$ = Initial mass release rate (kg/s)

W_o = Total mass released (kg)

τ_2 = $\frac{2}{3} \left(\frac{kfL^{1/2}}{D}\right) \frac{L}{C}$ = "Slow" time constant (see below) (s)

α = $W_o/\tau_2 \dot{m}_{oe}$ (dimensionless)

A_1 = $(1+\alpha)^{-1}$ (dimensionless)

k = Gas specific heat ratio (dimensionless)

f = Pipe friction factor (dimensionless)

D = Pipe diameter (m)

L = Pipe length (m)

C = $(kRT_1)^{1/2}$ = speed of sound (m/s)

T_1 = Pipe gas temperature

The first term in Equation 3-13 describes the initial fast release rate during the supersonic period; the last term describes the slower subsequent release rate. The time constant, τ_2, is typically one or two minutes for small pipes and less than ten minutes even for trunk lines.

The initial mass release rate, $\dot{m}_{oe}$, and total mass released, W_o, are functions of pipe length and diameter and the following state parameters for the gas:

F = Mass fraction of H_2S in the pipe gas

R = Gas constant

P_1 = Gas pressure

W_o = $FP_1 A_e L/RT_1$

$$\dot{m}_{oe} = FP_1 A_e \left[\frac{k}{RT_1} \left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}\right]^{0.5} \qquad (3\text{-}14)$$

A_e = $\pi D^2/4$ = pipe cross-sectional area.

Usually, the rupture is so severe that the area of emissions is simply the cross-sectional area A_e of the pipe. Field experiments show that the soil overburden is blown away in the first one or two seconds.

In practice, the effective pipe length may be much greater than the distance between the block valves if they require several seconds or longer to close completely. During this time period, gas from neighboring pipe sections will escape into the ruptured pipe section. This time delay can be accounted for by increasing the time constant τ_2 and the pipe length L used in the above expressions by an amount that depends upon the specifications of the block valves.

Plume Rise and Initial Source Effects

In a series of experiments with full-scale ruptured pipelines in Alberta (Alberta Petroleum Industry, Government Environmental Committee 1979a, 1979b), it was found that the pipe and the surrounding soil conduct sufficient heat to the gas in the pipe's interior to counteract the cooling effect of the gas as it does work to push escaping gas out of the rupture. As a result, the temperature of the gas in the pipeline remains approximately constant during the period of release. At the rupture, the gas is accelerated and its kinetic energy increases at the expense of internal energy, thus decreasing the gas exit temperature at the rupture.

As soon as the jet mixes with ambient air, however, this kinetic energy is quickly transformed into turbulence and subsequently back into heat (Briggs 1975). This temporary loss of buoyancy has a negligible effect on the gas motion; thus, the temperature of the gas can be assumed to be constant throughout its trajectory.

Therefore, to calculate Δh, the maximum plume rise, we can use the standard Briggs' formula for a momentum jet in a crossflow, as modified by Wilson (1981a):

$$\Delta h = \frac{2.9}{\beta_e} \quad \frac{F_m^{1/2}}{U_h} \tag{3-15}$$

and with the choice of entrainment coefficient $\beta_e = 0.6$ we get

$$\Delta h \quad = \quad 4.8 \; \frac{F_m^{1/2}}{U_h} \tag{3-16}$$

The momentum flux F_m can be written as

$$F_m \quad \approx \quad \left(\frac{1-k}{k}\right) F_{me} \tag{3-17}$$

where F_{me}, the momentum flux at pipe exit, is

$$F_{me} \quad = \quad \frac{\dot{m}_e \, w_e}{\pi \rho_a} \tag{3-18}$$

and w_e, the sonic exit velocity is given by

$$w_e \quad = \quad \sqrt{kRT} \tag{3-19}$$

Note that the mass flux $\dot{m}_e$ is here the total sour gas release rate, not the mass fraction of H_2S alone. The wind speed, U_h, at final plume rise can be calculated from the measured wind speed (e.g., at height h_o) with the conventional power law

$$U_h/U_o \quad = \quad (h/h_o)^n \tag{3-20}$$

where the power n is given as a function of Pasquill stability class in Table 3-9. In the computer model, plume rise is calculated iteratively from the first estimate for h, 75 meters.

It is not likely that the initial jet would be directed upward. Depending on the nature of the pipe rupture, the jet can be angled in any direction and may be deflected from the wall of the earthen crater that is blasted away in the first second or two after the pipe bursts. Consequently, the plume rise equation gives the maximum rise; the actual rise is likely to be

TABLE 3-9

ESTIMATES OF POWER n FOR SIX STABILITY CLASSES

	A	B	C	D	E	F
n	0.10	0.15	0.20	0.25	0.30	0.30

TABLE 3-10

FORMULAE FOR σ_y AND σ_z
(x Equals Downwind Distance in Meters)

Pasquill Type	σ_y, m	σ_z, m
A	$0.22x(1 + 0.0001x)^{-1/2}$	$0.20x$
B	$0.16x(1 + 0.0001x)^{-1/2}$	$0.12x$
C	$0.11x(1 + 0.0001x)^{-1/2}$	$0.08x(1 + 0.0002x)^{-1/2}$
D	$0.08x(1 + 0.0001x)^{-1/2}$	$0.06x(1 + 0.0015x)^{-1/2}$
E	$0.06x(1 + 0.0001x)^{-1/2}$	$0.03x(1 + 0.0003x)^{-1}$
F	$0.04x(1 + 0.0001x)^{-1/2}$	$0.016x(1 + 0.0003x)^{-1}$

Source: Hanna, S. R., G. A. Briggs, and R. P. Hosker 1982. Handbook on Atmospheric Diffusion. DE8200 2045 (DOE/TIC-11223), U.S. Department of Energy.

less. To conservatively cover the entire range of plume rise, maximum ground-level concentrations for the largest pipes were calculated on the basis of nominal 20-meter, 50-meter, 100-meter, and 200-meter plume rise, as well as maximum plume rise.

The plume expands initially because of self-generated turbulence. For elevated plumes, the effective σ_{xo} and σ_{zo} at the height of final rise equal about 0.4 Δh (15 to 67 meters for the plumes in the Alberta field experiment). For ground-level sources, the initial puff is observed to have a diameter of about 20 meters, or effective σ_{xo} and σ_{zo} of about 10 meters.

Calculations of Downwind Ground-Level Concentrations

Because the transport and diffusion of gas emitted from a rupture is represented by an expanding transient cloud or puff, the conventional Gaussian formula used to calculate ground-level concentrations must first be modified to account for along-wind diffusion (σ_x) and the time-varying release rate ($\dot{m}_e$):

$$C = \frac{\dot{\bar{m}}}{\pi U_c \sigma_y \sigma_z} e^{-y^2/2\sigma_y^2} e^{-\Delta h^2/2\sigma_z^2} \tag{3-21}$$

where U_c is the mean convective speed. A power law is used to estimate U_c, where $z_c = \Delta h + 0.17\,\sigma_z$. The term $\dot{\bar{m}}$ (kg/s) represents the effective mass flux taking into account along-wind diffusion and the time varying release rate.

Equation 3-13 shows that the <u>initial</u> mass flux is the sum of two exponential terms. Because the centroid of the 'puff' is advected with wind speed U_c, each term can be written in the form

$$\dot{m}_i\ (x,t) = \frac{\dot{m}_{oi}}{2} \exp\left(\frac{\sigma_x^2}{2U_c^2\tau_i^2} - \frac{x - U_c t}{U_c\tau_i}\right) \tag{3-22}$$

$$\cdot \left[\operatorname{erf}\left(\frac{x}{\sqrt{2}\,\sigma_x} + \frac{\sigma_x}{\sqrt{2}U_c\tau_i}\right) - \operatorname{erf}\left(\frac{(x - U_c t)}{\sqrt{2}\,\sigma_x} + \frac{\sigma_x}{\sqrt{2}U_c\tau_i}\right)\right]$$

where the index i ranges from 1 to 2, the terms τ_1 and τ_2 are time constants, and mass emissions $\dot{m}_{oi}$ are

$$\dot{m}_{o1} = A_1 \dot{m}_{oe}, \quad \dot{m}_{o2} = A_1 W_o/\tau_2 \qquad (3\text{-}23)$$

The error functions (erf) can be found in standard statistical tables.

The total effective mass flux is given by:

$$\dot{m}(x,t) = \dot{m}_1(x,t) + \dot{m}_2(x,t) \qquad (3\text{-}24)$$

This term has the biggest effect on the "nose " of the mass flux, decreasing the magnitude of the peak by about 50 percent and diffusing it forward so that the first influence of the H_2S arrives at a receptor at a time prior to the time calculated by straightforward advection of the initial pipe burst (see Figure 3-4).

The along-wind diffusion parameter σ_x has three components:

σ_{xt} = the turbulence induced along-wind spread,

σ_{xs} = the component resulting from along-wind speed shear,

σ_{xo} = the component associated with effective initial source size.

Wilson (1981b) uses the following expressions for σ^2_{xt} according to Gifford (1976):

Unstable and Neutral Classes: $\sigma^2_{xt} = 6\,\sigma^2_{zt}$

Stable Classes: $\sigma^2_{xt} = 10\,\sigma^2_{zt}$

For σ^2_{xs} Wilson uses

$$\sigma^2_{xs} = 0.09\left[\frac{n_x}{z_r}\left(\frac{z_r}{z_c}\right)^n\right]^2 \sigma^2_{zt}$$

In the above expressions

n = the exponent in the wind power law

σ_{zt} = the turbulence-induced vertical dispersion coefficient

$z_r = \Delta h + 0.50\,\sigma_z$ (an empirical expression)

$z_c = \Delta h + 0.17\,\sigma_z$ (an empirical expression)

The shear term, σ_{xs}, is allowed to grow with downwind distance in the model until σ_z is 100 meters and the plume is effectively out of the surface layer. At distances beyond which σ_z is 100 meters, the shear term is held constant and σ_x grows only due to turbulence-induced along-wind spread.

Taking into account the initial source size in the crosswind and vertical dimensions, the complete set of equations for σ_x, σ_y, σ_z are then

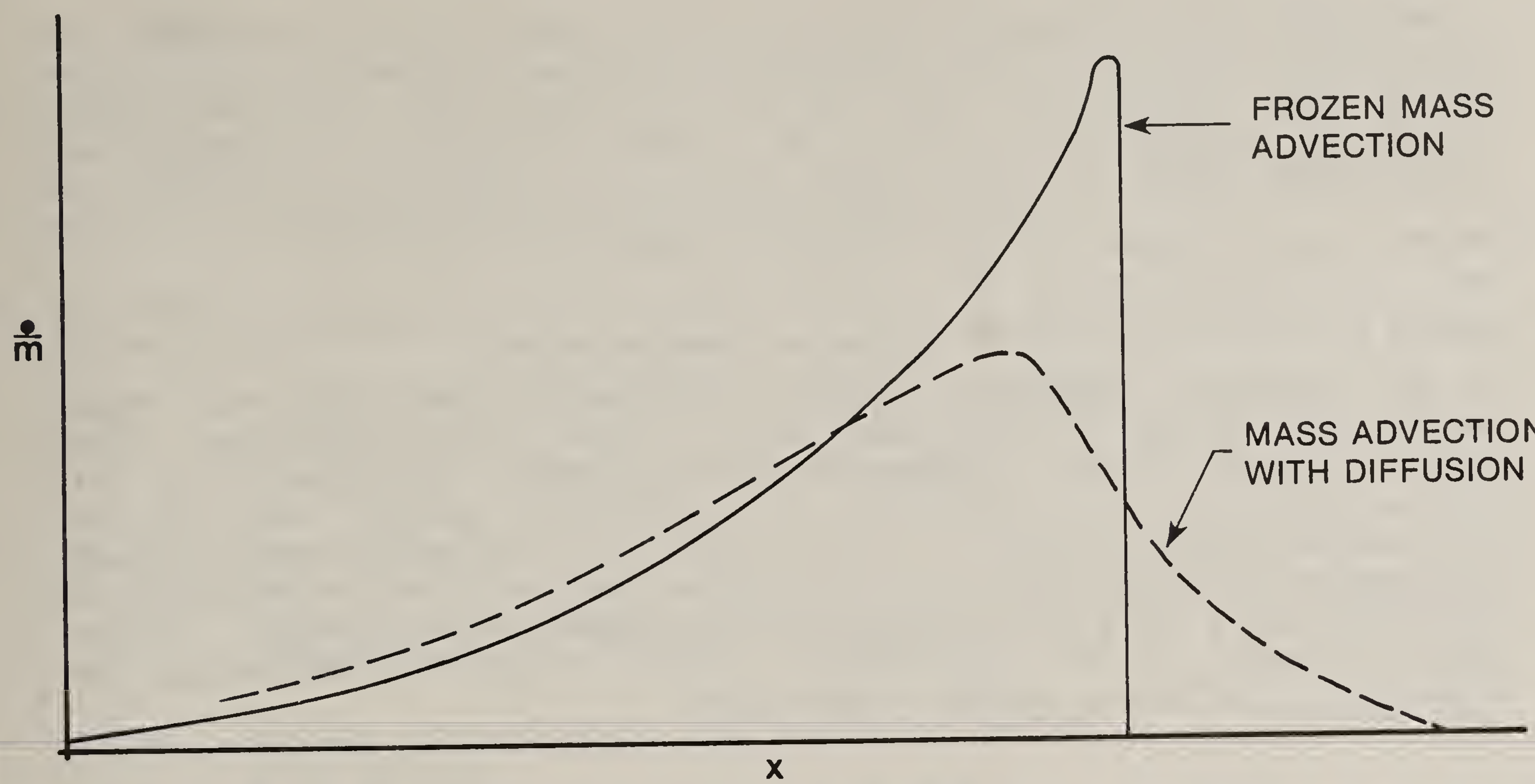


FIGURE 3-4 EFFECT OF DIFFUSION ON MASS ADVECTION FROM PIPELINE BURST

TOTAL DOSAGE IS OBTAINED BY INTEGRATING FROM T_1 TO T_2. THE MAXIMUM OBSERVED CONCENTRATION FOR AVERAGING TIME Dt IS OBTAINED BY AVERAGING FROM T_3 TO T_4.

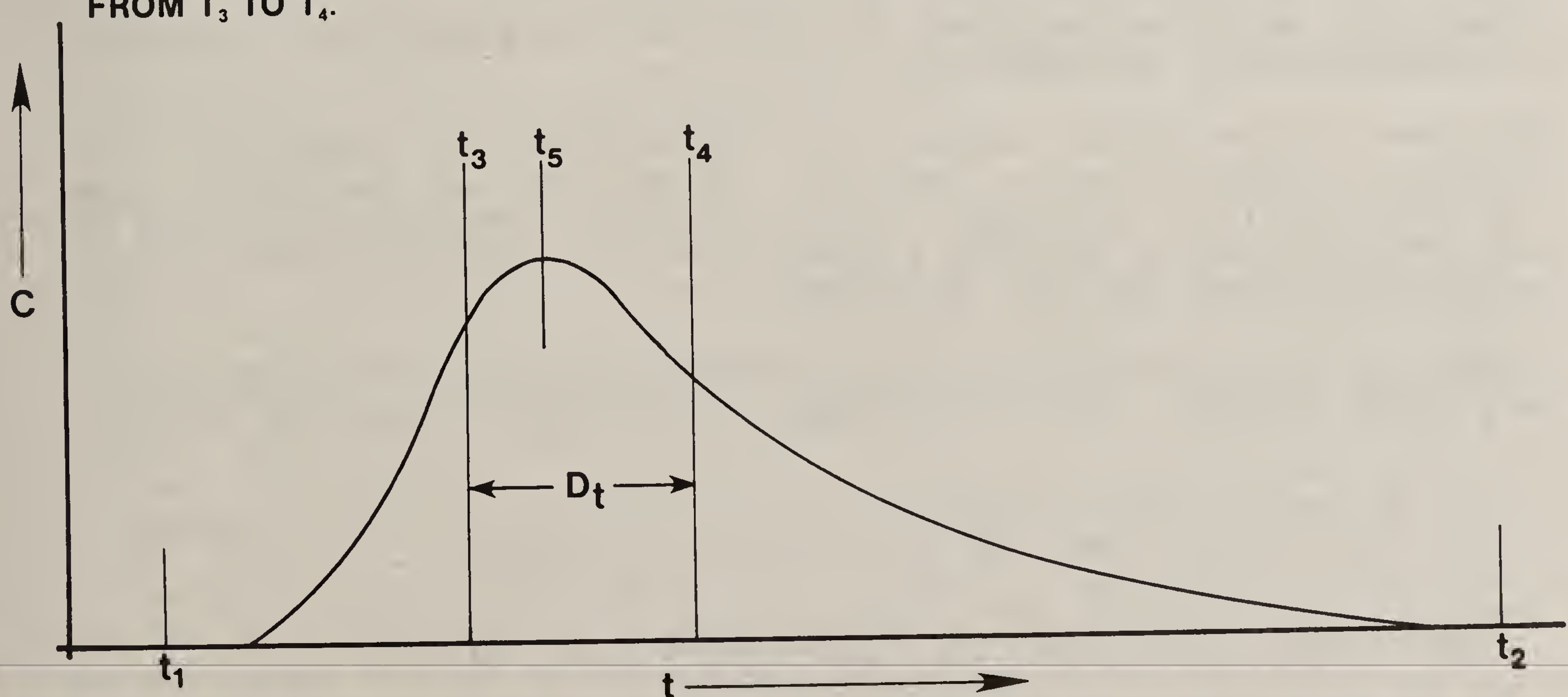


FIGURE 3-5 CONCENTRATION VS. TIME OBSERVED AT A GIVEN RECEPTOR.

$$\sigma_x^2 = \sigma_{xt}^2 + \sigma_{xs}^2 + \sigma_{xo}^2 \quad (3\text{-}25)$$

$$\sigma_y^2 = \sigma_{yt}^2 + \sigma_{yo}^2 \quad (3\text{-}26)$$

$$\sigma_z^2 = \sigma_{zt}^2 + \sigma_{zo}^2 \quad (3\text{-}27)$$

The empirical formulae for σ_{yt} and σ_{zt} are given in Table 3-10.

Methods of Calculating Concentration and Dosage Patterns

The H_2S toxicity information given in Table 1-1 indicates that each concentration level is associated with a time average exposure. For example, since 1,000 parts/million can cause immediate loss of consciousness, it is important to calculate spatial patterns of instantaneous concentrations. In this case it is also necessary to account for turbulent fluctuations in concentrations, as the formulae discussed to this point apply only to ensemble mean concentration predictions. Wilson (1979) suggests the use of Csanady's (1973) methods for estimating the intensity, i_c, of concentration fluctuations:

$$i_c = \sqrt{\overline{C'^2}}/C = i_{co}\, e^{\pm y^2/4\sigma_y^2} \quad (3\text{-}28)$$

where i_{co} is the "fluctuation intensity" on the plume centerline. Field and laboratory experiments suggest that the centerline intensity, i_{co}, is equal to about 1.0. The expected maximum concentration can be assumed to equal:

$$C_{max} = C\ (1 + i_c) \quad (3\text{-}29)$$

where C_{max} is defined such that 84 percent of instantaneous concentrations are expected to be less than C_{max}.

For lower concentrations, dosages or averaging times that range from a few minutes to several hours are important. Because most of the material from the pipe rupture is discharged in less than 10 minutes, the total dosage at any receptor within about 10 kilometers of the source is, effectively, experienced within less than 30 minutes.

Figure 3-5 illustrates the expected curve of concentration versus time at any given receptor. The total dosage, D, is given by the time integral

$$D\ (\mu g\ sec/m^3) = \int_{t_1}^{t_2} C dt \quad (3\text{-}30)$$

The average concentration over the period $\Delta t = t_2 - t_1$ is:

$$C = D/\Delta t = \left(\int_{t_1}^{t_2} C dt\right)/\Delta t \quad (3\text{-}31)$$

For averaging times Δt that do not include the entire C(t) dose curve in Figure 3-5, the maximum average concentration over Δt can be estimated by proper choice of the time limits t_3 and t_4. In addition, the average concentration for averaging time Δt at any time can be easily calculated. For averaging times greater than a few seconds, it is no longer necessary to account for turbulent fluctuations in concentration.

The model used can calculate the spatial (x, y) distribution of the following variables:

- maximum instantaneous concentration, independent of time;
- instantaneous concentrations at a given time after release;
- total dosage;
- maximum average concentration for averaging period Δt, independent of time; and
- average concentration for averaging period Δt at a given time after release.

In addition, the variation of concentration as a function of time at a given receptor can be calculated.

Meteorology and Dispersion

A range of meteorological conditions were simulated for the pipeline rupture dispersion modeling. These conditions cover the feasible range of stability categories and wind speeds, including light winds with extreme instability, neutral conditions with moderate and high winds, and stable light wind conditions. Modeling results are presented for a 3-meter/second wind speed and unstable stability, a 5-meter/second wind and neutral stability, and a 2-meter/second wind with stable stability.

Model Input Parameters

The pipeline parameters proposed by each applicant are presented in Table 3-11. This table lists each applicant's information regarding pipe sizes, lengths, pressures, valve close times, and pipe friction factors. Other input parameters to the model not listed in Table 3-11 include: pipe gas temperature, the gas constant (dependent on the effective molecular weight), the specific heat ratio (C_p/C_v), and the mass fraction of H_2S in the gas. All applicants except Northwest indicate gas temperatures would be approximately equal to the ambient air temperature, with a minimum value in winter of 37°F. Northwest's information for gas temperatures gives 135°F for the 6-inch pipe, 120°F for the 12-inch pipeline, and roughly ambient for the 29-inch pipe. The gas constant depends on the molecular weight of the gas and ranges from 227 to 232 N·M/Kg°K for the different applicants. There is considerable uncertainty in the information available concerning the gas specific heat ratio k. A detailed thermodynamic analysis made with nominal average percentages for sour gas composition in the Riley Ridge field, together with other nominal assumptions about pipeline temperature and pressure, leads to the value k = 3.5. This value, which falls within the

TABLE 3-11

INPUTS TO THE PIPELINE RUPTURE DISPERSION MODEL

Applicant	Pipe Diameter (inch)	Length Between Block (mile)	Valve Close Time (sec)	Total Pipe Length (mile)	Pipe Friction Factor	Pressure (psi)
Exxon	4.16	3	18	87	0.0165	1,200
Exxon	6.15	3	30	8	0.0150	1,200
Exxon	8.13	3	36	9	0.0120	1,200
Exxon	12.25	4	60	13	0.0100	1,200
Exxon	15.38	3	78	7	0.0098	1,200
Exxon	19.25	10	96	57	0.0095	1,200
Exxon	23.25	10	120	32	0.0090	1,200
Quasar	36	10	60	25	0.0090	1,000
Quasar	30	10	60	11	0.0090	1,510
Quasar	22	6	60	6	0.0090	1,689
Quasar	6	3	60	30	0.0150	1,595
Northwest	30	2.5-5	60	43	0.0090	1,830
Northwest	12	3	(manual)	NP	0.0100	1,830
Northwest	6	1	(manual)	NP	0.0150	1,830

NP = Not Provided

2.5 to 5.7 range of k values provided by Exxon, has been used consistently throughout. Exxon supplied information on the specific heat ratio which indicates a range of 5.7 to 2.5 for a temperature range of 37 to 75°F, under 1,200 pounds/square inch of pressure. The applicants' information on H_2S in the sour gas range from 3.2 percent for Exxon to 4.5 percent for Northwest, on a molar or volume basis. Actual H_2S percentages on a mass basis were used for each pipeline.

Minimum plume rise was assumed for the final pipeline rupture dispersion modeling. The data available on pipeline ruptures (Knox et al. 1980) indicate minimum plume rise is of order 20 meters for 6 to 12-inch diameter pipes and 50 meters for larger pipes. To provide conservative predictions of H_2S concentrations, these nominal plume rises were assumed throughout the modeling.

Gathering Line Dose Sensitivity Analysis

This section presents H_2S concentrations from gathering line ruptures. These concentrations are used together with the probability of ruptures and meteorological conditions to quantify the health and safety consequences described in Chapter 2.

First, each applicant's 6-inch diameter pipe was modeled in order to examine the sensitivity of the predictions to a range of H_2S content in the gas, pipeline pressures, and block valve spacings. Instantaneous H_2S concentrations predicted to occur downwind during light wind stable conditions are shown in Figure 3-6. These predicted concentrations indicate that an increase in either pipeline pressure or H_2S content will cause a proportional increase in the downwind concentrations. When block valves are more closely spaced, H_2S concentrations are lower and decrease more rapidly with distance, particularly during stable low wind speed conditions.

The second step in the gathering line analysis was to examine the range of H_2S concentrations that might occur as a function of weather conditions and averaging time. For this purpose the Quasar 6-pipe was modeled for instantaneous and 15-minute H_2S concentrations. A 20-meter plume rise was assumed. The results for three weather conditions are plotted in Figure 3-7. As shown, 15-minute average H_2S concentrations are not predicted to exceed the 100 parts/million significance criterion regardless of the weather conditions. However, instantaneous concentrations would approach or exceed lethal levels near the pipe during any meteorological conditions.

The third step in the gathering line analyses was to examine the sensitivity of the predicted concentrations to a range of pipeline diameters and assumed plume rises. For this purpose, Exxon's 4-inch, 6-inch, 12-inch and 19-inch gathering lines were modeled. Instantaneous H_2S concentrations predicted to occur during low wind speed stable conditions are shown in Figure 3-8. Smaller pipes were modeled with a 20-meter plume rise. The 19-inch pipe was modeled with both a 20-meter and a 50-meter plume rise. As shown, the lower plume rise assumption increases the predicted concentration by a factor of 3.

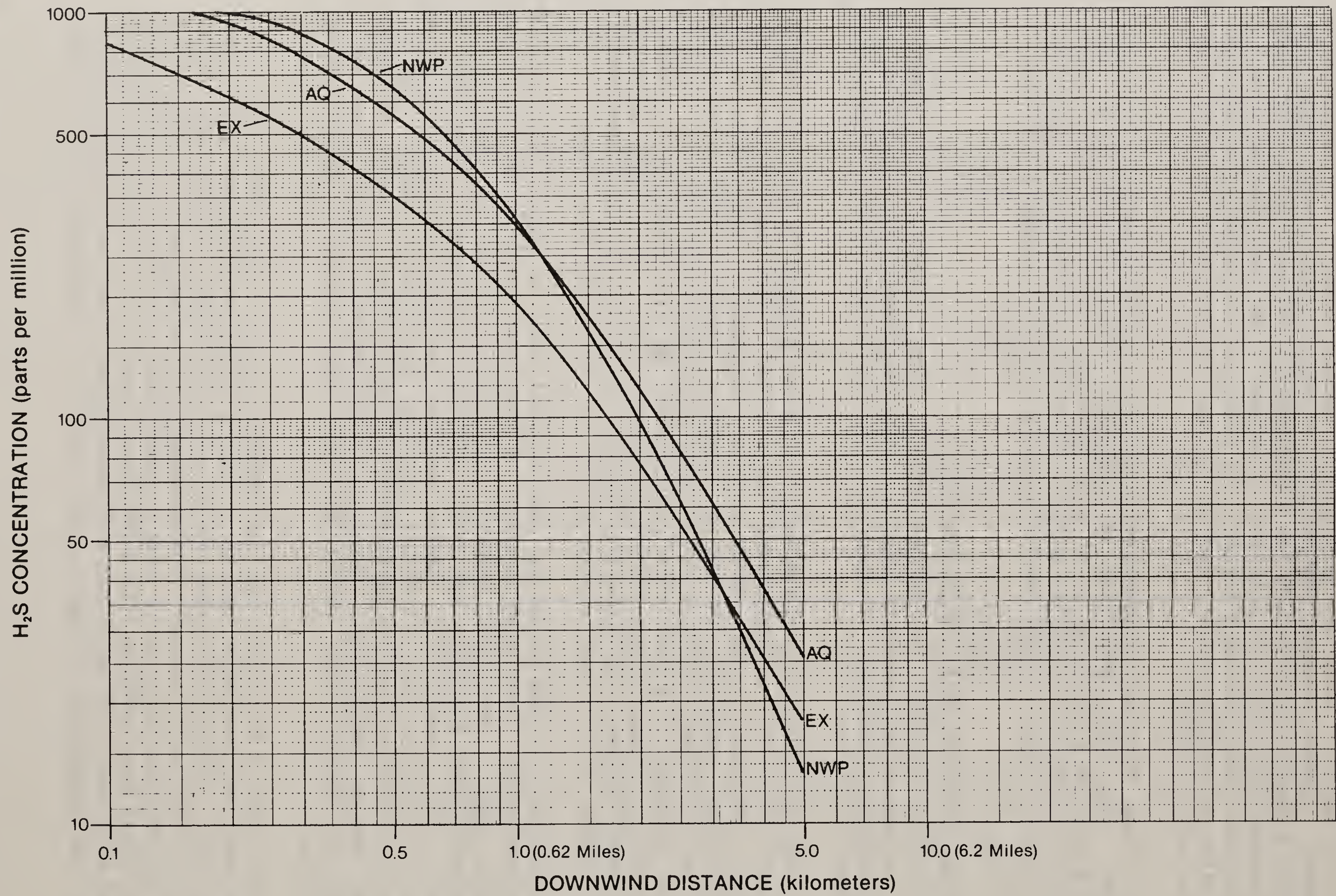


FIGURE 3-6 MAXIMUM INSTANTANEOUS H_2S CONCENTRATION PROFILES FOR 6-INCH PIPES DURING LIGHT WIND STABLE CONDITIONS

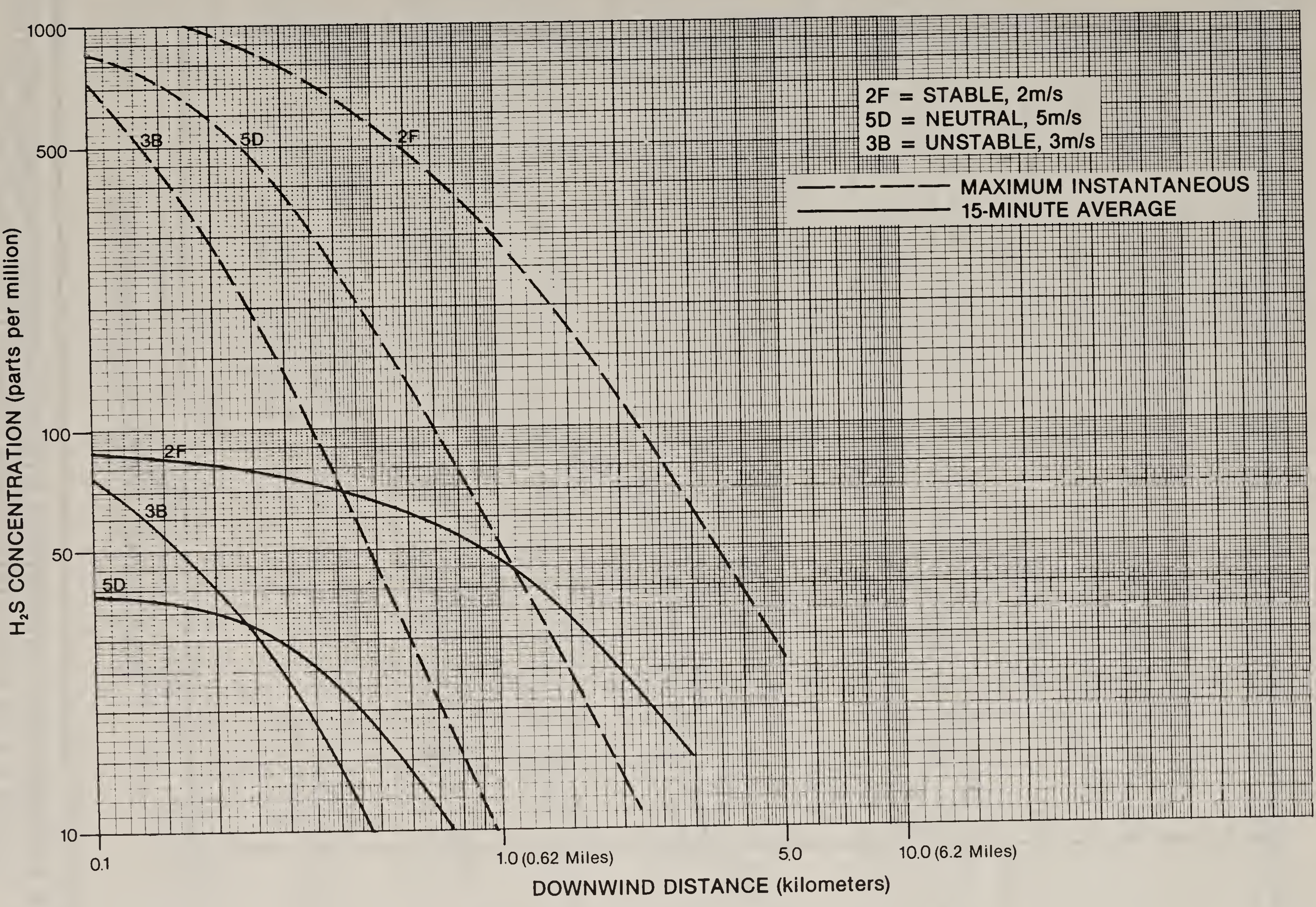


FIGURE 3-7 H_2S CONCENTRATION PROFILE FOR THE QUASAR 6-INCH PIPES FOR THREE METEOROLOGICAL CONDITIONS

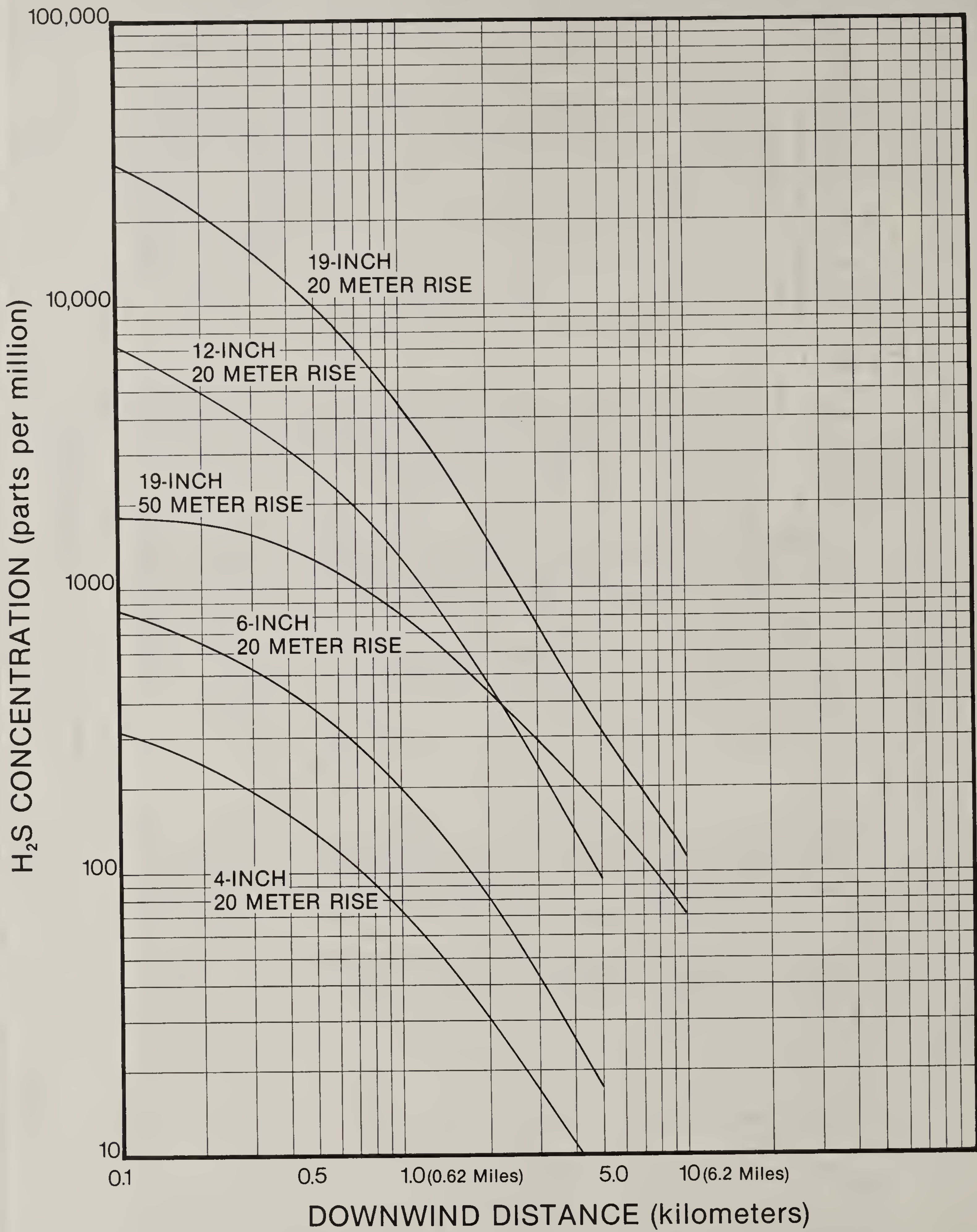


FIGURE 3-8 MAXIMUM INSTANTANEOUS H_2S CONCENTRATION PROFILES FOR THE EXXON 4, 6, 12, AND 19-INCH PIPES DURING LIGHT WIND STABLE CONDITIONS

Trunk Line Sensitivity Analysis

Various model runs were made for the applicants in order to determine the worst-case trunk line rupture scenarios. For the Proposed Action and alternatives these included:

- Quasar: 36-inch pipeline; 10-mile block valve spacing;
- Quasar: 30-inch pipeline; 10-mile block valve spacing;
- Northwest: 30-inch pipeline; 5-mile block valve spacing;
- Northwest: 30-inch pipeline; 2.5-mile block valve spacing in populated areas.

All trunk line modeling assumed a 50-meter plume rise. The downwind distances from trunk lines to concentrations equal to the significant criteria are summarized in Table 3-12. In this table (and elsewhere) the headings 2F, 5D, and 3B refer to the following meteorological conditions; 2 meters/second stable; 5 meters/second neutral; and 3 meters/second unstable.

PROBABILITY OF WORST-CASE METEOROLOGY

Since no meteorological record is presently available for the immediate vicinities of the population centers that may be exposed to some risk from a well blowout or pipeline rupture, data available from Fort Bridger and Rock Springs have been applied to the risk assessment in a very general and conservative manner; that is, to estimate the maximum possible likelihood of risks to the populated areas of LaBarge, Big Piney, the Fontenelle Recreation Area, and Calpet.

To estimate the frequency of near-surface, low wind speeds under stable conditions, the Rock Springs data are preferred because the measurements at Rock Springs were made at 10 meters, whereas the measurements at Fort Bridger were made at 20 meters. On the other hand, to estimate the directional frequencies of winds from the westerly sectors (the wind directions required to transport H_2S toward the population centers which lie generally to the east of the pipeline fields), Fort Bridger data are preferred, because Rock Springs is affected by valley circulation effects.

From the Rock Springs data, the observed 30 percent frequency of stable, low wind speeds (less than 4.5 meters/second) was used as a conservative upper bound estimate for the frequency of stable, light winds (less than 3 meters/second) in the immediate project area.

From the Fort Bridger data, fewer than 82 percent of all stable flows are westerly or northwesterly, and all are less than 10 meters/second. Accordingly, the 82 percent is considered a conservative upper bound estimate for the frequency of stable flows directed from the west or northwest in the immediate project area.

Therefore, the maximum probability for stable, light wind speeds directed from the project area toward the population centers of LaBarge, Big Piney, and the Fontenelle Recreation Area is estimated as 0.30 X 0.82, or 0.25.

TABLE 3-12

DISTANCES (MILES) FROM TRUNK LINES TO SIGNIFICANCE LEVELS AS A FUNCTION OF WEATHER CONDITIONS AND BLOCK VALVE SPACINGS

Applicant	Pipe Diameter (Inches)	Block Value Spacing (Miles)	1,000 Parts/Million Instaneous			500 Parts/Million Instaneous			100 Parts/Million 15-Min. Average		
			2F	5D	3B	2F	5D	3B	2F	5D	3B
Northwest	30	5	2.9	1.1	0.5	4.5	1.7	0.7	5.6	1.1	0.6
		2.5	2.2	0.9	0.4	3.4	1.5	0.6	2.4	0.4	0
Quasar	36	10	3.5	1.2	0.6	5.8	1.9	0.7	9.9	1.4	0.8
	30	10	2.5	0.9	0.4	4.4	1.4	0.6	6.8	1.0	0.7

2F = 2 meters/second stable
5D = 5 meters/second neutral
3B = 3 meters/second unstable

That is, the "meteorological" risk for worst-case conditions is at most 25 percent. This risk factor has been used where appropriate in the combined risk assessment discussed below.

The small town of Calpet is located just to the west of the proposed Northwest trunk line to Craven Creek and the Exxon alternative trunk line to Shute Creek. In order to assess the risk of H_2S exposure to the population of Calpet it was assumed that stable conditions occur 30 percent of the time, neutral conditions 40 percent of the time, and unstable conditions 30 percent of the time. No adjustments were made for wind direction. That is, it has been assumed (conservatively) that the wind always directs the release from a rupture toward the town.

RISK ANALYSIS METHODOLOGY

In order to estimate the risk to individuals caused by well blowouts or pipeline ruptures, the following equation was employed;

$$R = P_A P_W P_H \tag{3-32}$$

where

P_A = The probability of an accident

P_W = The probability that worst-case weather conditions would occur

P_H = The probability that the gas released would not rise to its maximum potential height

As described before, for purposes of this study it has been assumed that $P_H = 0.5$ for the well field drilling and pipeline ruptures. This assumption is based on the above-ground apparatus used during drilling and on the possibility that bottom ruptures and burial depth would constrain pipeline releases. Also as described before for well field production blowouts, P_H is assumed to be 0.2. This assumption is based on the limited surface obstructions in the well field during production.

Because a blowout is expected to continue for up to three days, the probability of worst-case weather conditions for blowouts is assumed to be one. If a pipeline rupture were to occur, the gas would be released very quickly, within a few minutes. Therefore, any weather condition could dominate the dispersion and transport of pipeline gas. The worst case would be a release during light wind stable conditions, and the probability of these conditions and adjustments applied for wind direction toward population centers was discussed in the previous section.

The equations used to estimate the probability of an accident, P_A, were discussed previously. The mile-years of pipeline used in these equations were based on either the total length of pipeline or the locations of critical population areas.

The proposed and alternative trunk lines would pass near, and possibly impact, four population centers: Big Piney, LaBarge, Calpet, and the Fontenelle Reservoir. If the distance from a trunk line to one of these populations centers was predicted to be less than the extent of a significant dose isopleth, the length of trunk line that would expose the population at this significance level was estimated. These lengths shown in Table 3-13 were used to estimate the probability of a rupture occurring.

For example, the western edge of LaBarge is located 2.2 miles east of Northwest's Craven Creek trunk line. Northwest has proposed using 2.5-mile block spacings near population centers. For this block valve spacing distances from the trunk line to significant H_2S levels for instantaneous and 15-minute average H_2S concentrations can be read from Table 3-12. The distances at which dose concentrations would become less than the significance criteria are:

Significance Criteria	Distance (Miles) 2F	5D	3B
500 Parts/Million Instantaneous	3.4	1.5	0.6
100 Parts/Million 15-min. Average	2.4	0.4	0

2F = 2 meters/second stable
5D = 5 meters/second neutral
3B = 3 meters/second unstable

Similarily, the distances at which dose concentrations would be less than the lethal dose are:

Lethal Dose	Distance (Miles) 2F	5D	3B
1,000 Parts/Million Instantaneous	2.2	0.9	0.4

Based on the distance to LaBarge, only light wind stable conditions would cause a significant impact if a rupture were to occur. Furthermore, lethal doses are unlikely. Discomfort levels are most conservatively described by the 500 parts/million isopleth which could extend 3.4 miles from the trunk line. The miles of trunk line that are less than 3.4 miles from LaBarge were measured and found to be 5.3 miles.

Thus, using equation 3-3, the probability of one or more ruptures occurring over a year was estimated to be (5.3 miles) x (1/5,000 ruptures per mile-year) or 0.00106, or about 0.1 percent.

TABLE 3-13

LENGTHS OF TRUNK LINES IMPACTING POPULATION CENTERS USING WORST-CASE DISPERSION CRITERIA

Populated Area	Applicant	Trunk Line End Point	Lethal Dose or Significance Criteria[1] (Parts/Million)	Trunk Line Length (miles) Impacting the Populated Area for Various Block Valve Spacings: 10 miles	5 miles	2.5 miles	Shortest Distance from Population Center to Trunk Line (miles)
LaBarge	Northwest	Craven Creek	1,000	--[2]	3.9	0	2.2
			500	-	7.8	5.3	
			100	-	10.4	2.1	
	Exxon[3]	Shute Creek	1,000	2.7	-	-	
			500	7.7	-	-	
			100	13.0	-	-	
Calpet	Northwest	Craven Creek	1,000	-	5.8	4.4	0
			500	-	8.9	6.8	
			100	-	11.2	4.8	
	Exxon	Shute Creek	1,000	5.0	-	-	
			500	8.8	-	-	
			100	13.7	-	-	
Big Piney	Quasar	Buckhorn	1,000	0	-	-	6.2
			500	0	-	-	
			100	16.0	-	-	
	Quasar	East Dry Basin	1,000	0	-	-	
			500	0	-	-	
			100	3.1	-	-	

TABLE 3-13 (CONTINUED)

Populated Area	Applicant	Trunk Line End Point	Lethal Dose or Significance Criteria[1] (Parts/Million)	Trunk Line Length (miles) Impacting the Populated Area for Various Block Valve Spacings: 10 miles	5 miles	2.5 miles	Shortest Distance from Population Center to Trunk Line (miles)
Fontenelle Recreation Area	Northwest	Craven Creek	1,000	-	0	0	3.8
			500	-	4.0	0	
			100	-	7.1	0	
	Exxon	Shute Creek	1,000	0	-	-	
			500	3.7	-	-	
			100	10.1	-	-	

[1]1,000 parts/million lethal dose and 500 parts/million significance criteria are for instantaneous concentrations, whereas 100 parts/million significance criterion is for 15-minute average concentrations.

[2]Non-applicable block valve spacing.

[3]Exxon's Shute Creek Alternative trunk line is assumed to have impacts equivalent to Quasar's 30-inch pipe.

LaBarge is located to the east of the pipeline so the probability of worst-case weather would be 0.25. The probability that the modeled plume rise of 50 meters would occur is estimated to be 0.5. Therefore, the annual probability that a person in LaBarge would be exposed to significant H_2S concentrations is (0.00106) X (0.25) X (0.5) = 0.00013, or about 0.01 percent.

The annual individual risks of lethal H_2S doses in populated areas from a rupture of a proposed or alternative trunk line are shown in Table 3-14. The risks of significant discomfort for each populated area are provided in Table 3-15. The methodology described above has been applied in a similar manner for blowout risks.

TABLE 3-14

ANNUAL INDIVIDUAL RISK OF LETHAL H_2S DOSES IN POPULATED AREAS FROM A RUPTURE OF A PROPOSED OR ALTERNATIVE TRUNK LINE

Populated Area	Applicant	Plant Site	P_A	P_W	P_H	R
LaBarge	Northwest	Craven Creek	0	0.25	0.5	0
	Exxon	Shute Creek	0.00054	0.25	0.5	0.000068
Big Piney	Quasar	East Dry Basin	0	0.25	0.5	0
	Quasar	Buckhorn	0	0.25	0.5	0
Fontenelle Rec. Area	Northwest	Craven Creek	0	0.25	0.5	0
	Exxon	Shute Creek	0	0.25	0.5	0
Calpet	Northwest	Craven Creek	0.00088	0.30	0.5	0.00013
			0.00038	0.40	0.5	0.000075
			0.00018	0.30	0.5	0.000026
						0.00023
	Exxon	Shute Creek	0.001	0.30	0.5	0.00015
			0.00038	0.40	0.5	0.000075
			0.000026	0.30	0.5	0.000026
						0.00025

$$R = P_A P_W P_H$$

where P_A = The probability of an accident

P_W = The probability that worst-case weather conditions would occur

P_H = The probability that the gas released would not rise to its maximum potential height

TABLE 3-15

ANNUAL INDIVIDUAL RISK OF SIGNIFICANT IMPACTS FROM H_2S IN POPULATED AREAS FROM A RUPTURE OF A PROPOSED OR ALTERNATIVE TRUNK LINE

Populated Area	Applicant	Plant Site	PA	PW	PH	R
LaBarge	Northwest	Craven Creek	0.0011	0.25	0.5	0.00013
	Exxon	Shute Creek	0.0026	0.25	0.5	0.00033
Big Piney	Quasar	East Dry Basin	0.00062	0.25	0.5	0.000077
	Quasar	Buckhorn	0.0032	0.25	0.5	0.00040
Fontenelle Rec. Area	Northwest	Craven Creek	0.0014	0.25	0.5	0.00018
	Exxon	Shute Creek	0.0020	0.25	0.5	0.00025
Calpet	Northwest	Craven Creek	0.0014	0.30	0.5	0.00021
			0.00060	0.40	0.5	0.00012
			0.00025	0.30	0.5	0.000037
						0.00037
	Exxon	Shute Creek	0.0027	0.30	0.5	0.00041
			0.00058	0.40		0.00012
			0.00025	0.30	0.5	0.000038
						0.00056

$$R = P_A \, P_W \, P_H$$

where P_A = The probability of an accident

P_W = The probability that worst-case weather conditions would occur

P_H = The probability that the gas released would not rise to its maximum potential height

REFERENCES

Alberta Petroleum Industry, Government Environmental Committee. 1979a. Hydrogen sulphide isopleth prediction, phase 1: model sensitivity study. Alberta Department of Environment.

Alberta Petroleum Industry, Government Environmental Committee. 1979b. Hydrogen sulphide isopleth prediction, phase 2: pipe burst study. Alberta Department of Environment.

American Conference of Governmental Industrial Hygienists, Inc. 1980. Documentation of the threshold limit values. Fourth edition.

American Gas Association. 1980. An analysis of reportable incidents for natural gas transmission and gathering lines 1970 through 1978.

American Petroleum Institute. 1978. Safe drilling of wells containing hydrogen sulfide. Washington, D. C.

American Petroleum Institute. 1981. API recommended practices for conducting oil and gas production operations involving hydrogen sulfide. Washington, D. C.

Atwell, L. D. and W. B. Andrews. 1979. Risk assessment for sour gas facilities. Energy Resource Conservation Board, Calgary, Alberta, Canada.

Briggs, G. A. 1975. Research required for predicting the behavior of pressurized gases escaping into the atmosphere. Report 75-5, ATDL, Oak Ridge, Tennessee.

Csanady, G. T. 1973. Turbulent diffusion in the environment. Boston: D. Reidel Publishing Co.

de la Mare, R. F., and O. Anderson. 1980. Pipeline reliability, Det Norske Veritas. August.

Gifford, F. A. 1976. Turbulent diffusion typing schemes: review. Nuclear Safety 17: 68-86.

Hanna, S. R., G. A. Briggs, and R. P. Hosker. 1982. Handbook on atmospheric diffusion. DE 82002045 (DOE/TIC-11223), U.S. Department of Energy.

Hollub, Sonny. 1982. Data received from the Texas Railroad Commission.

Jossi, David. 1982. Data received from Information Systems Division, Research and Special Programs Administration, U.S. Department of Transportation, Washington, D.C.

Knox, H. W., L. D. Atwell, R. Angle, R. Willoughby, and J. Dielwart. 1980. Field verification of assumptions for modeling sour gas pipeline ruptures and well blowouts. Paper presented at the 31st Annual Technical Meeting of the Petroleum Society of CIM in Calgary, May 25-28, 1980.

REFERENCES (CONTINUED)

Layton, David W., Environmental Sciences Division, Lawrence Livermore National Laboratory, Livermore, California. October 4, 1982. Personal communication.

Minerals Management Service. 1982. Onshore oil and gas program series. U.S. Department of the Interior.

National Institute for Occupational Safety and Health. 1977. NIOSH criteria for recommended standard . . . .occupational exposure to hydrogen sulfide. U.S. Department of Health, Education, and Welfare.

Occupational Safety and Health Administration. 1978. Occupational health guidelines for hydrogen sulfide. U.S. Department of Labor.

Roberts, Wendy E., and Ian Cameron, Environmental Protection Department, Energy Resources Conservation Board, Calgary, Alberta, Canada. 1982. Personal communication.

U.S. Army Corps of Engineers. 1982. Production of natural gas from the lower Mobile Bay Field, Alabama, final environmental impact statement.

U.S. Department of Transportation. 1977, 1979, 1980. Annual report on pipeline safety. Materials Transportation Bureau, Washington, D. C.

Wilson, D. J. 1979. The release and dispersion of gas from pipeline ruptures. Research Report for Pollution Control Division, Alberta Environment.

Wilson, D. J. 1981a. Expansion and plume rise of gas jets from high pressure pipeline ruptures. Research Report for Pollution Control Division, Alberta Environment.

Wilson, D. J. 1981b. Along-wind diffusion of source transients. Atmospheric Environment 15: 489-485.

APPENDIX A

BLM CHECKLIST FOR DRILLING AND PRODUCTION FACILITIES

GUIDELINES FOR H_2S CONTINGENCY PLAN PREPARATION

The purpose of the plan is to provide an organized plan of action for alerting and protecting employees and the public following an accidental release of a potentially hazardous volume of hydrogen sulfide. The plan is not a checklist of equipment and players but a game plan; a plan of action; a logical step-by-step approach to an emergency. The plan will also help to prevent over-reaction and the bringing in of unnecessary people when the operator may have the capability to handle the problem. Whenever the radius of exposure includes a public area or is equal to or exceeds 3,000 feet, a contingency plan is required.

Some of the things a plan should include are listed below. The list is not in order of importance, and some items may not apply to every plan, but a plan may include the following:

1. Instructions for alerting employees and the public of an emergency.

2. Procedure for requesting assistance and follow-up action to remove the public from the area of exposure.

3. A call list of people to notify of an emergency:

		Phone Numbers	
Internal List	Name	Office	Home
Production Supt.			
Drilling Supt.			
Field Engineer			
Lease Operator			
External List			
Ambulance			
Hospital			
Doctor			
Dept. of Public Safety			
Police or Fire Dept.			
BLM			
DEQ and/or OSHA			
Contractors and Service Companies (include name and type equipment available)			

CHECKLIST FOR DRILLING OR WORKOVER IN H_2S ENVIRONMENT

(Pending Approval of Proposal NTL-10)

Items 1-4 to be shown on site layout diagram (part 9 of NTL-6 13-point checklist.

1. Two safety briefing areas at least 200 feet from wellhead and arranged so that at least one area will always be upwind of the well at all times.

2. Direction of prevailing winds.

3. Wind sock locations. (Minimum of 2) (NTL-10. 11-1(4))

4. A second emergency escape route from the location, (Flagged trail minimum).

5. Number of types, and storage locations of H_2S respirators for personnel, and number of personnel to be expected at any one time.

6. H_2S detector locations (should at least include cellar or bell nipple and mud tanks at shale shaker). Type and location of audible, visual alarm to be used. (NTL-10. 11-1(3))

7. H_2S evacuation and emergency training procedures and frequency. (NTL-10. 11-A(1)(B))

8. Area residents within a two-mile radius, and agencies to be notified in an emergency (contingency plan). (NTL-10. I-D)

9. Types and quantities of mud additives and scavengers to be available at locations for H_2S operations.

10. Design features and operational procedures to be used to protect the drill string, casing strings, wellhead, BOPs, choke lines and manifold, and other well-killing equipment in H_2S environment. (A certification by the operator on the APD that all equipment meets standards for H_2S service is acceptable for compliance).

11. Appropriate warning signs and flags on all access roads to location. (NTL-10 11(4))

12. Provisions for blocking or monitoring access to location during critical operations.

13. Ventilation fan under rig floor.

14. In event of uncontrolled blowout, which local official has authority to ignite flow?

15. Swabbing or drillstem testing fluids containing H_2S should be through a separator to permit flaring of gas. Flare should have continuous pilot light to insure ignition of all such gas.

H_2S CHECKLIST FOR PRODUCING LEASES
(Pending approval of proposed NTL-10)

1. Obtain gas analysis at wellhead or separator to determine concentration of H_2S.

2. If concentration exceeds 20 ppm (0.002 percent by volume), the following protective measures should be considered:

   A. Warning signs and fencing around appropriate facilities.

   B. If flowing wells, high-low wellhead control, subsurface safety valve or equivalent automatic controls should be considered in the event of surface malfunction.

   C. If flowing well, there should be two mast valves in series on tubing head.

   D. If flowing well and H_2S concentration is 100 ppm or more, use radius of exposure formula (NTL-10) to determine limit of exposure. Based on this determination, if appropriate, a contingency plan should be prepared and available in the event of an accidental release of sour gas. If several leases or a field is involved, a composite contingency plan may be more appropriate than individual plans (see attached guidelines for H_2S contingency plans).

   E. Any unconfined gas produced during testing or swabbing should be separated and flared. There should be a pilot light on all sour gas flares to insure continuous ignition. If H_2S is very potent, a water spray at flare pit should be considered to control SO_2.

   F. Proper breathing apparatus should be available and used when working in an H_2S environment exceeding 20 ppm.

   G. Storage tanks are not subject to radius or exposure formula requirements. Safeguards should be considered, however, such as:

      1) Fencing with ladder gate and appropriate warning signs.

      2) Dual ladder-catwalks with wind sock for upwind access.

NOTE: Implementation of many of these items require judgement on the part of the District Supervisor and depend on the severity of conditions. Such as proximity to populated areas, or public facilities, terrain, type, and condition of well (oil, gas, flowing, pumping) etc.

4. Plat of area showing radius of exposure, location of public areas, location of evacuation routes, and location of safety equipment and telephones.

5. List of names and telephone numbers of residents within the area of exposure and the person responsible for any public area.

6. Provision of advance briefing of public within an area of exposure. This briefing should include information on the hazards and characteristics of hydrogen sulfide, possible sources, instructions for reporting a leak, and the manner in which the public will be notified of an emergency. If several operators have leases with overlapping radii, this briefing should be coordinated so there will not be a lot of duplication and unnecessary contacts.

7. Detailed operating procedures to be followed in an emergency, including specific job assignments for personnel.

8. Detailed remedial procedures to be followed in an emergency.

9. Rules for when protective equipment such as clothing, fresh air breathing equipment, gas detectors, etc., is required to be used by personnel.

10. A plan should include conditions of weather, differences in terrain and covering vegetation, and seasonal changes that might create an increase in hazardous conditions or an abnormal dispersion pattern.

In the event of a high density of population, or where the population density is unpredictable, the reaction plan will be acceptable in lieu of a contingency plan. The main difference between a contingency plan and a reaction plan is that the reaction plan does not require the advance briefing of the public. This plan must be approved by the District Engineer, USGS, prior to implementation.

Any plan should be kept close to where the action might be and readily available to operating personnel. The plan should be short, simple, and as workable as possible, so that the man in the field can understand it, and quickly find the portion needed in case of an emergency. A working knowledge of the plan by all personnel is desirable. Information on the plan should be included with safety training programs.

Any plan, no matter how well conceived, will need to be updated from time-to-time. Periodic reviews should be made to keep all portions of the plan current, especially the call list.

☆U.S. GOVERNMENT PRINTING OFFICE:1983—676-071 / 1004